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GEOLOGIC AND ENGINEERING PROPERTIES OF PLEISTOCENE MATERIALS IN IOWA

by
D. T. Davidson
and
Associates

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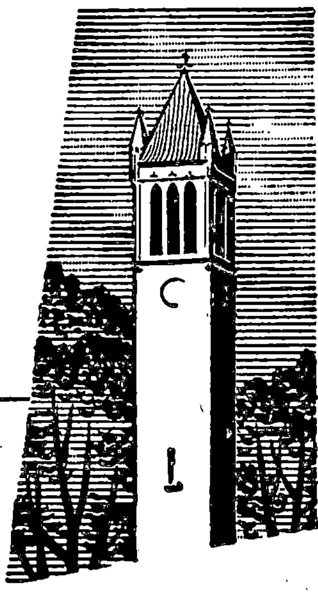

IOWA ENGINEERING EXPERIMENT STATION

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AMES, IOWA

Geologic and Engineering Properties of Pleistocene Materials in Iowa

by

D. T. Davidson, Professor, Civil Engineering
and Associates

(Eleven related manuscripts)

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PREFACE

The state of Iowa does not have enough economically available supplies of sand, gravel, and rock to meet the road building needs of the present and future. Though certain counties have been favored more than others with aggregate deposits, this statement applies to the entire state, if a long-range viewpoint is taken. Many other sections of the United States, as well as many foreign countries, are faced with a similar shortage. A solution to this problem is to learn how to treat or process readily available materials to increase their all-weather stability for road construction.

In Iowa the abundance and wide distribution of loess and glacial till materials makes them the logical ones with which to start working.

This bulletin is a compilation of the reports on completed research done for the Iowa State Highway Research Board Project HR-1, "The Loess and Glacial Till Materials of Iowa; an Investigation of Their Physical and Chemical Properties and Techniques for Processing Them to Increase Their All-Weather Stability for Road Construction." The research, started in 1950, was done by the Iowa Engineering Experiment Station under its project 283-S. The project was supported by funds from the Iowa State Highway Commission.

The principal objectives of the project may be summed up as follows:

1. To determine by means of both field and laboratory studies the areal and stratigraphic variation in the physical and chemical properties of the loess and glacial till materials of Iowa.

2. To develop new equipment and methods for evaluating physical and chemical properties of soil where needed.

3. To correlate fundamental soil properties with the performance of soils in the highway structure.

4. To develop a scientific approach to the problem of soil stabilization based on the relationships between the properties of the soils and those of the admixtures.

5. To determine the manner in which the loess and glacial till materials of Iowa can be processed for optimum performance as highway embankments, sub-grades, base courses, and surface courses.

Many of the papers in this bulletin were prepared originally as graduate theses required for master or doctoral degrees. Each was then re-written with the assistance of other project workers and was submitted to the Iowa Highway Research Board as a report on a phase of completed research. This explains the several authors for each paper. The research work was all done under Dr. D. T. Davidson as project leader in charge.

Practically all the papers herein have been published previously. The title page for each manuscript identifies all authors and gives the place and date of first publication. No attempt has been made to revise, update, and change the data; hence some contradictions are evident. The facts and conclusions presented are those of the authors at the time the manuscript was submitted. Much of the repetition of material has been eliminated, and the papers have been arranged by subject matter.

The list of REFERENCES at the end of each manuscript gives only the first, or original printing, though the paper referred to may have appeared later in various forms in several publications, and some are included herein. Those shown as theses in the Iowa State University Library are so indicated because only in the theses are all the data shown.

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ANALYSIS OF WIND-BLOWN SILTS

by

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D. T. Davidson, Professor, Civil Engineering

(Iowa Academy of Science Proceedings 61:278-290. 1954)

Most geologists, we are told, believe that loess deposits were carried and placed by the wind. This, therefore, seems a logical place at which to start this series on engineering soils research, though it is not the first report

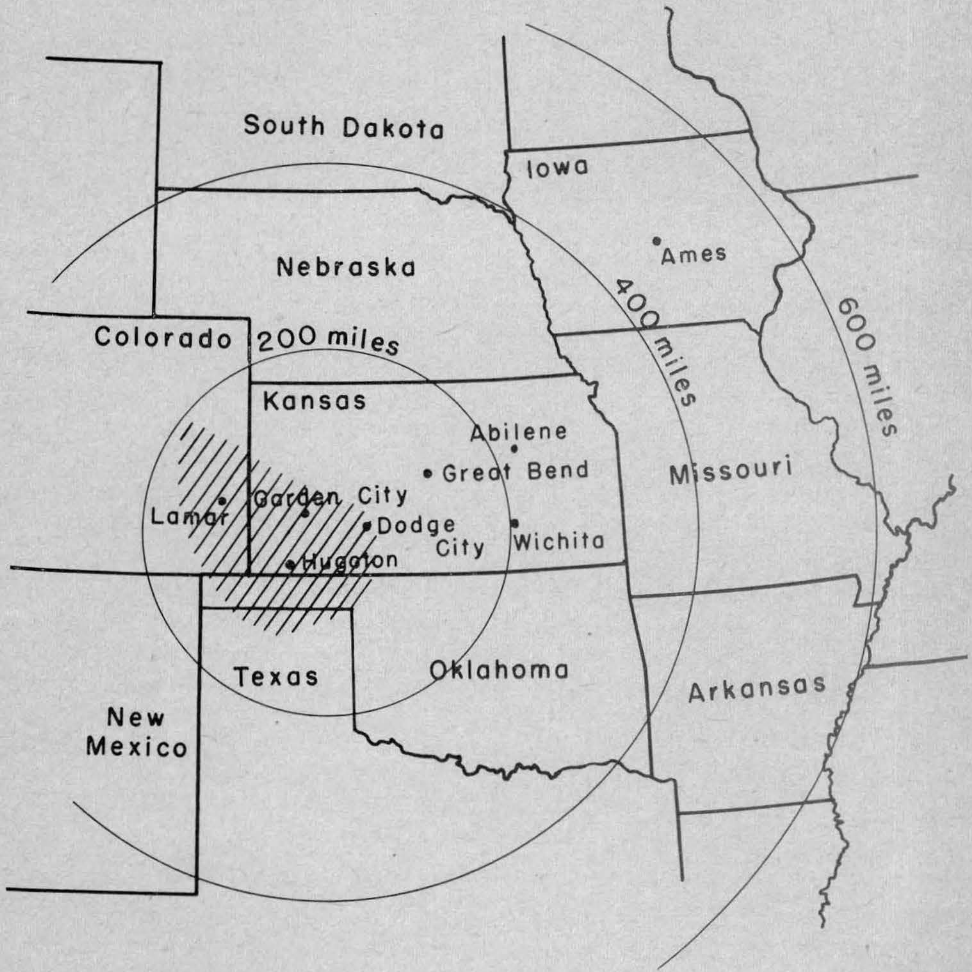

Fig. 1. Map of the major dust area observed during the March, 1954, storms. Dust area is shown by shading; the circles indicate radial distances.

Fig. 2. Dust blowing from a wheat field near Great Bend, Kansas. Sample No. 1 was obtained at this location.

of the work conducted on the project by the Soils Laboratory of the Iowa Engineering Experiment Station from 1950 to 1960.

Seeing silt-laden winds in action means visiting dust storms, and opportunities for study have been infrequent during the past fifteen years. In 1954 dust storms were again plentiful in the southwest. The combination of drought and strong winds sent dust from Kansas and Colorado into many Mid-Western states, and an average depth of one-sixteenth inch was deposited in Iowa from one storm.

Two of the authors who were studying dust which settled in Ames visited the most severe dust areas of southwestern Kansas and the Oklahoma and Texas panhandles. The purpose of the trip was to obtain some sand samples for a separate stabilization study, and to locate some dust storms.

THE DUST-BOWL AREA

Dust Storms.

The major area of the March, 1954, dust storms is shown in figure 1. Sources for the sand and silt were plowed fields which either were laid aside to prevent overproduction or had inadequate vegetative cover. Farther south in Texas the wheat crop was more advanced, and dusting was less. The dust sources were many separate plowed fields. As in the 1930's, the principal causes for the dust storms in 1954 appear to be drought and overcultivation. Plowing or furrowing had both loosened the soil and contributed to air turbulence near the ground, causing the soil grains to be more easily picked up. Figure 2 shows dust from a single field; the dust was blowing across an adjacent highway, and headlights were required. On either side of the field the air was clear. Valleys sometimes were, in effect, funnels for the wind and dust (figure 3).

Sand Drifts.

In the dust area, fences clogged with tumbleweeds formed barriers to the wind, and fine sands were deposited in drifts on the lee side of the fences, some of which were almost buried (figure 4). Fine sands also filled a few roadside ditches, and it was these sands which drifted across highways and railroad tracks to stop traffic. Only a few instances of actual traffic interruptions have been publicized, because the sands have been no worse than a few inches of snow.

Visibility.

A much greater traffic hazard was the reduced visibility near source areas of the dust during the most severe storms. Visibility was sometimes reduced to a few tens of feet or even less, and travel was virtually impossible due to the likelihood of getting lost. Some residents described the storms as the worst since the 1930's; others said they were even worse. According to the Soil Conservation Service conditions in 1954 were equal to the worst of the 1930's in number of acres blowing. However, the dust bowl conditions had not yet been prolonged through so many years, and the drought had not been associated with economic ruin, as in the "Dirty '30's."

Fig. 3. View of dust funneling through a stream valley near Junction City, Kansas.

Dust Clouds.

Dust trails can often be traced away from source areas, much as smoke can be traced from a faulty incinerator. Going away from the source area, the trails tend to coalesce into clouds of dust, and the dust is often carried to elevations of one to four miles. Dust clouds may persist for hundreds of miles, and have been observed as far east as the Atlantic coast.

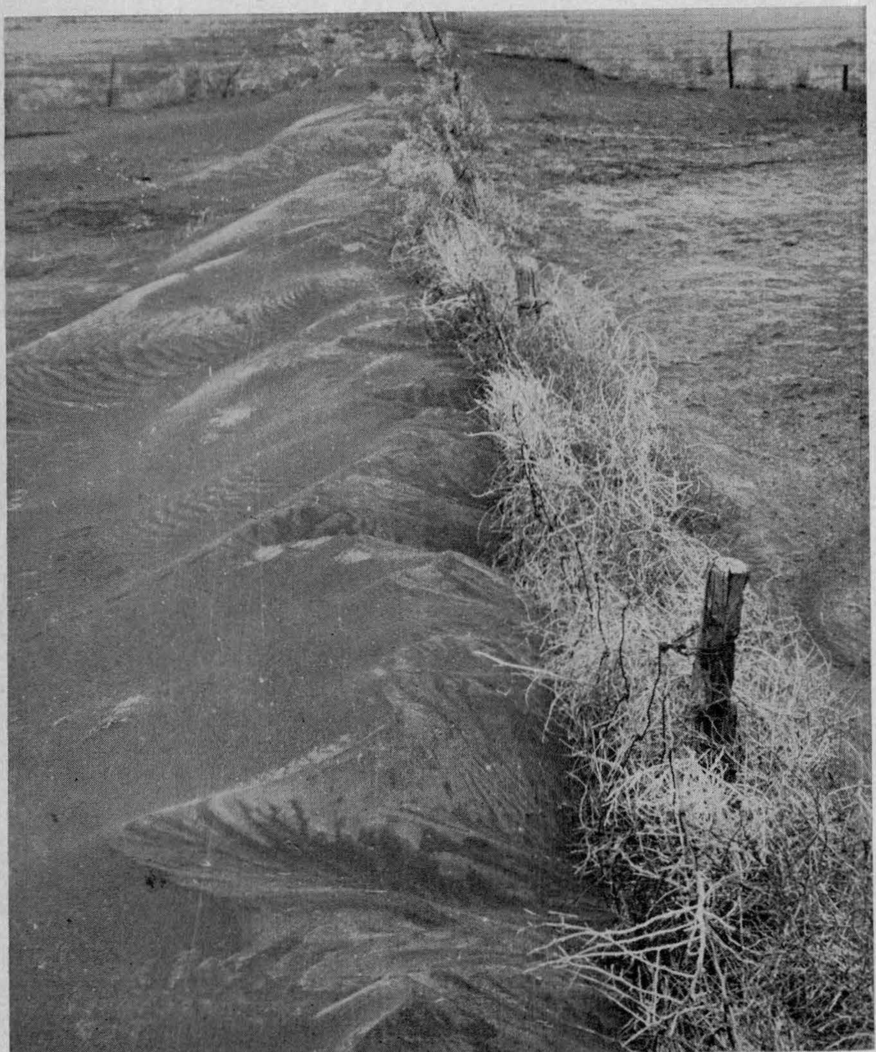

Fig. 4. Fences clogged with tumbleweeds and drifted with sand and sand-size aggregates of topsoil. The photo was taken south of Garden City, Kansas, near the Oklahoma state line. Particle-size curves for this sand are labeled "B" in figures 9 and 10.

A dust cloud blew over and through Dodge City, Kansas, on March 18, 1954, which was an especially good (or bad) day for dust storms. The sun was blotted out and darkness fell, as did large amounts of dust. Wherever the wind velocity was diminished, as in window corners and doorways, silt was deposited, to a depth of one-eighth inch on outside window ledges where screens served to lower the wind velocity. No rain or precipitation accompanied the dust fall. Many downtown sidewalks were hosed off with water, and the silt blocked storm sewer inlets and clogged gutters.

SAMPLING

At the Source.

Source areas for the silt (figure 2) are easily found and easily sampled. The sampling technique followed was to park the car downwind, spread out papers on the seats, and open a window approximately one inch. Near Great Bend, Kansas, about 15 gm. of dust was thus collected in a few minutes from the papers alone. For comparison, a sample of topsoil was taken from the adjacent source field. Several samples were obtained in the source area from sands which were drifted to the lee of fences, behind tufts of vegetation, in road ditches, and in similar locations, and from the topsoil sources of the sands.

Near the Source.

Two samples of silt were collected from window ledges, one in Garden City and the other in Dodge City, Kansas. Since the yield was about one-half pound at each sample location, risk of contamination was slight. Both samples were taken the day after deposition.

Far from the Source.

Unusual conditions in Ames, Iowa, resulted in a sudden deposition of dust on March 12. The dust was brought down by snow and hail. The snow then melted slowly and evaporated, leaving dust-derived mud on roof tops, windows, and automobiles. Dried dust was collected from two cars which had been washed just prior to the storm.

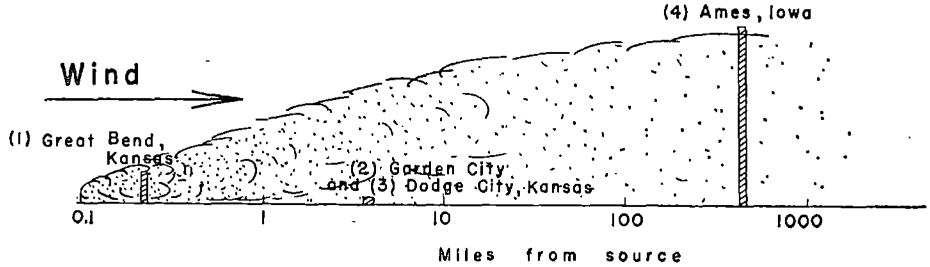

Fig. 5. Hypothetical dust storm showing materials represented by the various dust samples collected. Numbers in parenthesis are those of samples taken. Distances are shown to a logarithmic scale and are only approximate.

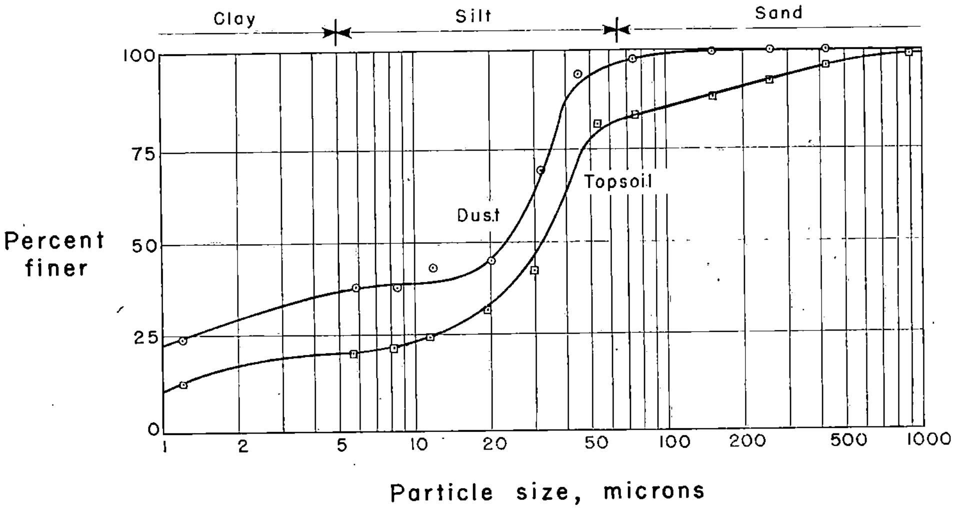

Fig. 6. Particle-size distribution curves for dust blowing from the field shown in figure 2, and for topsoil from the same field. The curves are similar except that the dust contains very little sand.

Sampling—Summary

The dust samples studied were collected in different manners and have different relationships to the storms. Samples 1 and 4 represent dust captured from suspension in the air (figure 5). Samples 2 and 3 represent coarse silts which dropped out of the air near the source.

PARTICLE SIZES

Methods of Analysis.

Mechanical analyses of the dust and soil samples were performed by hydrometer and sieve methods used on the loess[5]. Where the usual 50 gm. sample was not available, the dispersing agent was reduced proportionately. The dispersion for mechanical analysis is designed to obtain as complete a separation of grains as possible without significant breaking up of particles[4]. This is desirable for engineering purposes, since it gives a maximum indication of clay, the active soil fraction; otherwise the clay remains in the form of aggregates and coatings, and is not distinguished from silt. However, analyses of this type performed on an eolian sediment probably do not give a true indication of particle size during deposition. Even mixing an eolian sediment with water will result in some dispersion, and a reliable settlement analysis would be impossible unless done in a dry medium such as air. The wet method of measuring particle size is therefore of value mainly for making comparisons.

Dust.

The particle-size curves for dust collected from the air near Great Bend,

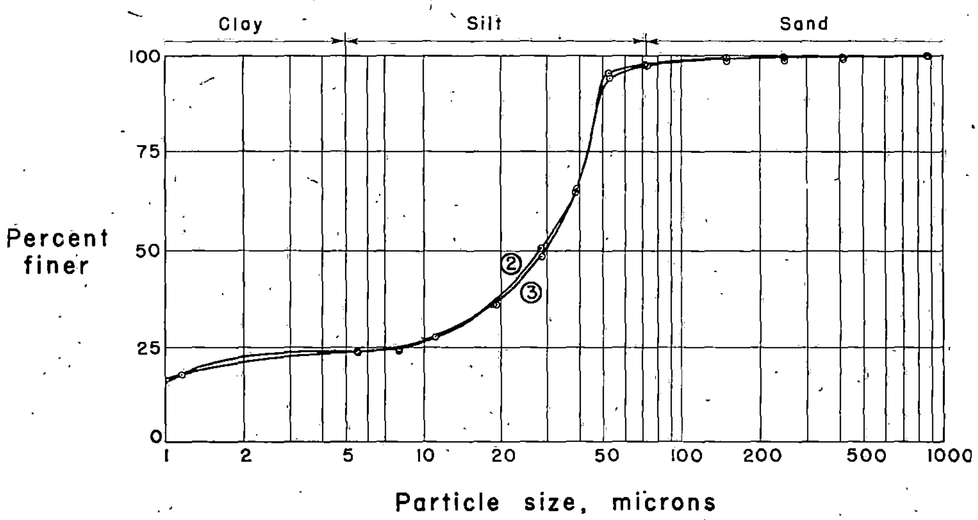

Fig. 7. Particle-size distribution curves for dust collected in Garden City (2) and Dodge City (3), Kansas.

Kansas, and for the topsoil source of the dust are very similar except for the sand content (figure 6). They illustrate the selective action of the wind in removing silt and clay from the topsoil and leaving the sand.

According to the laws governing particles settling in a suspension, coarse material settles fastest. Particle-size curves for dust which settled out of the air at Garden City and Dodge City, Kansas, (figure 7) are for samples collected fifty miles apart and deposited at different heights (on first and

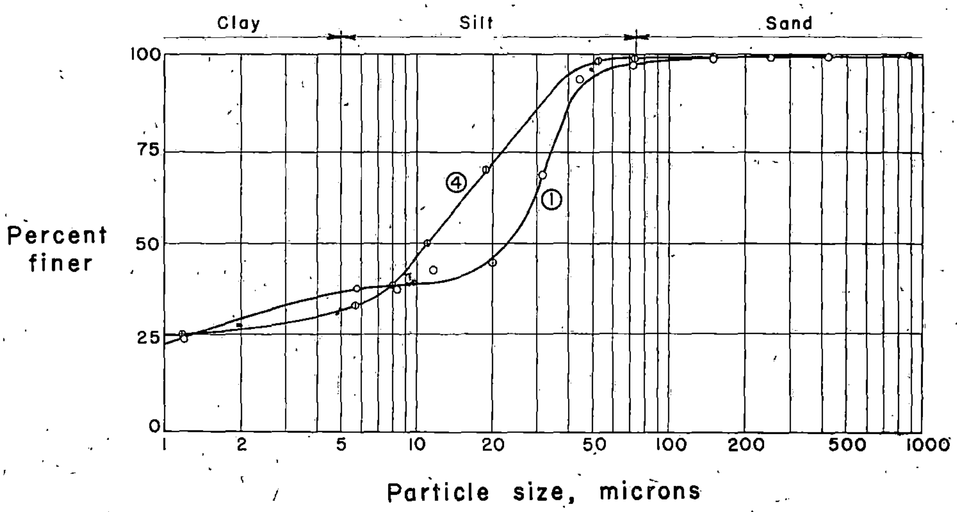

Fig. 8. Particle-size distribution curves for dust collected at Ames (4), Iowa and near Great Bend (1), Kansas.

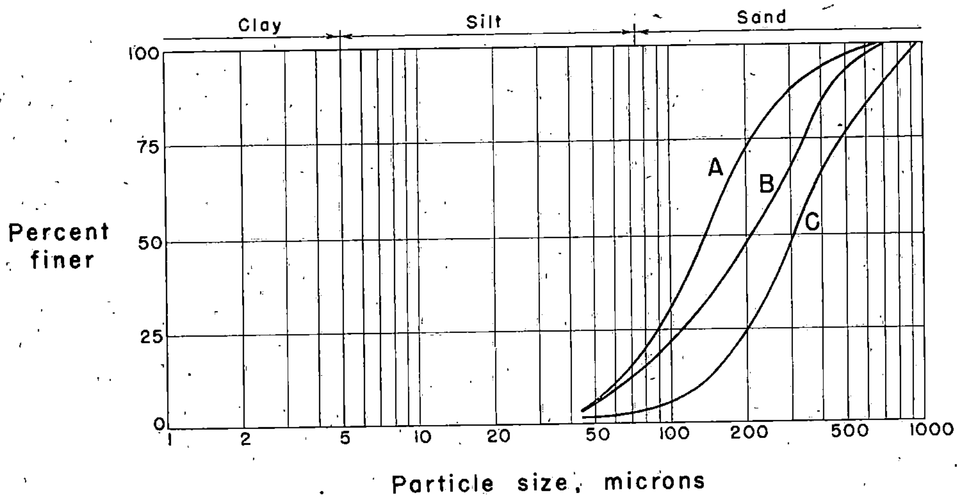

Fig. 9. Particle-size distribution curves obtained by dry-sieving three "sands" from fence-line drifts in the dust-bowl area.

third floor window ledges respectively) by winds from different directions on different days. Yet the curves are practically identical and indicate large amounts of coarse silt in these deposits. Since fine materials settle less rapidly, they were presumably carried away in the wind. Unfortunately, no accurate data are available on distances from the sources of these two samples. However, the two dusts probably are approximate first ma-

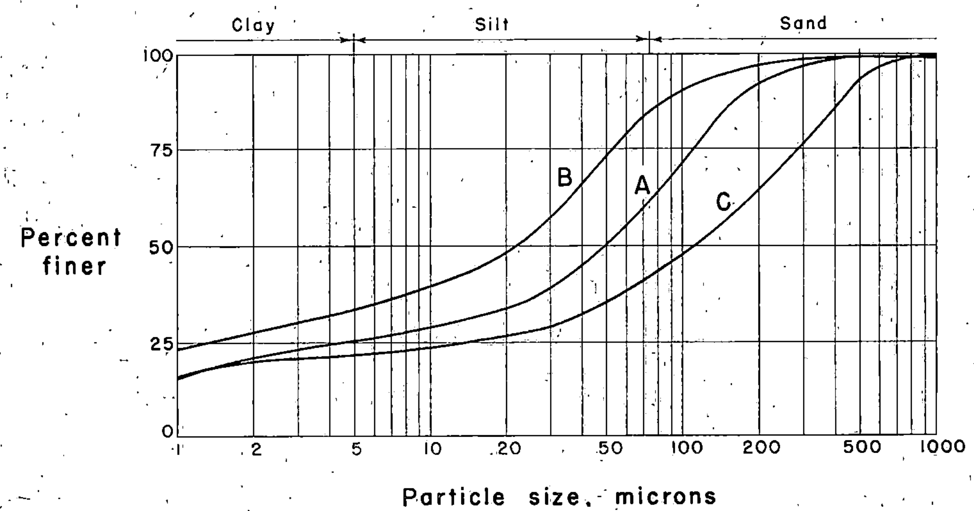

Fig. 10. Particle-size distribution curves for the same materials as in figure 9. These curves were obtained by conventional mechanical analysis with dispersion, and show that some of the drift "sands" are composed mainly of aggregates of silt and clay.

terials deposited, which would explain the similarity and coarseness in particle-size. The storms were associated with strong turbulent winds which normally would not permit extensive deposition. The winds therefore probably retained dust in suspension until such obstacles as trees and buildings in the two cities lowered the wind velocity sufficiently to allow the coarse material to settle.

Farther away from the source, one would expect the dust remaining in suspension to be progressively depleted of coarse material. While no settlement dust samples were obtained to illustrate this, the dust brought down in snow in Ames, Iowa, does give a satisfactory indication of air sorting. The sample of this dust (no. 4) is comparable to the Great Bend sample (no. 1) collected at the source, since both represent blowing dust. The Ames dust is much finer than that from Great Bend (figure 8).

The Great Bend sample represents dust blowing from only one source, and dust mixed in from other sources might change this curve somewhat. However, the changes to produce curve 4 material from curve 1 material involve a great decrease in coarseness of the silt, and such a decrease is improbable without wind sorting. Sorting by natural processes is further indicated by the straightline logarithmic relationship in the silt size range of curve 4.

Sand.

In the Dust Bowl area sand is too coarse to be suspended and blown into the next state, but it is often bounced along into the next field or until it drifts behind a fence (figure 4). Particle-size curves were determined by dry-sieving three such drift sands (figure 9). The analyses were repeated

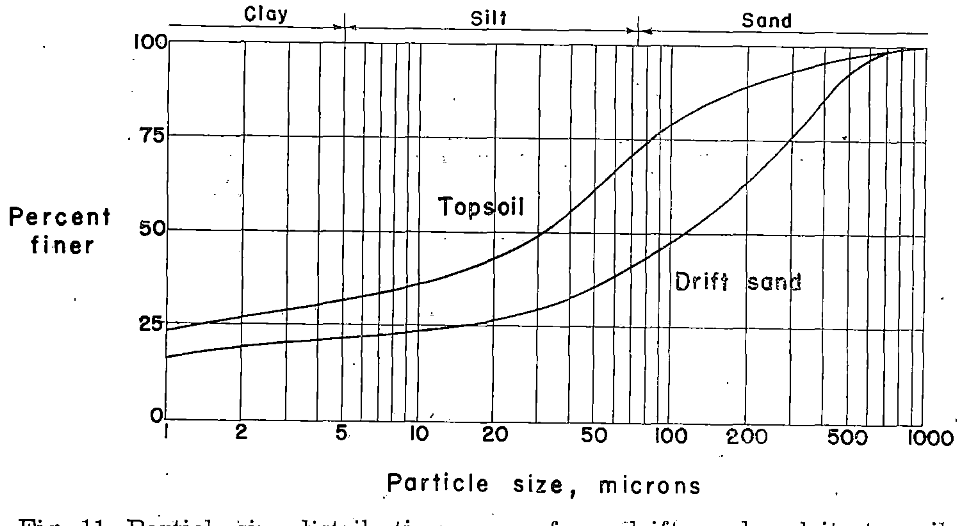

Fig. 11. Particle-size distribution curves for a drift sand and its topsoil source. Note the loss of fine materials when topsoil is eroded and drifted by the wind.

by sieving and hydrometer tests after dispersion with sodium metaphosphate[5]. The "sands", when the aggregates are broken and the grains dispersed, contain between 40 and 85 percent silt and clay; that is, the drift sands are mainly aggregates of topsoil. Previous experiences in the 1930's indicate that the sand-size aggregates become finer after repeated reworking by wind. It has been suggested that the sandy, poorly sorted paha loess in eastern Iowa is similar in origin to these drift sands[8]. Particle-size curves for one of the sands and for the topsoil source of the sand (figure 11) show that the drift sand is coarser than the topsoil, indicating removal of fine materials as dust.

MINERALOGICAL COMPOSITION

Differential Thermal Analysis.

Differential thermal curves for dust samples 2, 3, and 4 are presented in figure 12. The reactions are labelled on the bottom curves. All samples contain large amounts of organic matter, as indicated by the broad exothermic humps between 225°C and 600°C. Since this oxidation reaction masks others in that range, particularly the clay, the tests were repeated in a nitrogen atmosphere to inhibit oxidation. Curves for samples 2 and 3 from Garden City and Dodge City, Kansas, show the presence of organic matter and quartz and probably montmorillonite.

The curve for sample 4, from Ames, Iowa, shows similar but larger organic matter and clay mineral reactions. Quartz and calcite are also indicated.

Microscopic Examination.

Three of the dust samples were analyzed under a petrographic microscope and percentage determinations were made (table I). The dust samples were mounted in balsam without any pretreatment or size separation of the samples. High feldspar contents of samples 2 and 3 probably indicate

TABLE I. MINERALOGICAL COMPOSITION OF THREE WIND-BLOWN SILTS.
(Percent by volume of untreated, whole sample).

	Dust Samples and Location		
	No. 2 Garden City	No. 3 Dodge City	No. 4 Ames, Iowa
Quartz	63.9	14.5	64.0
Feldspar, undifferentiated	23.8	71.1	9.0
Mica (Biotite and muscovite)	0.8	1.3	3.2
Heavy minerals*	4.3	3.4	5.8
Clay aggregates	5.2	8.5	12.0
Others			
Calcite	0.4	----	2.8
Opal	1.3	0.5	2.1
Volcanic glass	----	0.6	0.9

Remarks: Clay coatings on grains are common. Feldspars are predominately of the potash type. Organic material is abundant in all samples.

* Separated by visual examination only.

rather localized source areas, particularly sample 3, with over 70% feldspar. Specific source areas cannot be identified, but materials such as opal and volcanic glass in the Iowa sample point to a distinctly western origin.

Clay in the three dust samples is found mainly as coatings on the silt grains, although aggregations of clay and organic matter are also common. Isolated grains of clay were quite rare. Heavy minerals in eolian dusts were not found by some[11], but have been reported by other investigators[1, 7].

COMPARISON OF DUST AND LOESS

Similarities in particle-size composition of loess and of eolian dusts have been demonstrated many times, but few investigators have pointed out differences. Dusts resulting from contemporary dust-bowl conditions are

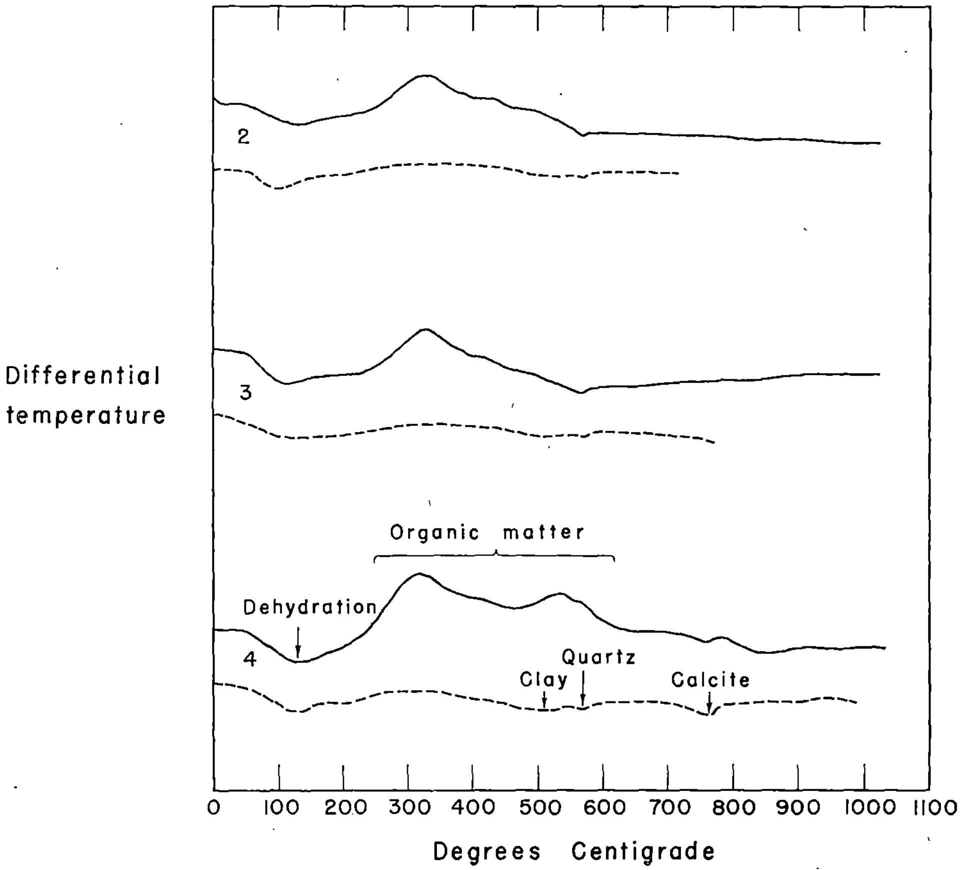

Fig. 12. Differential thermal curves for three dust samples from Garden City and Dodge City, Kansas, and from Ames, Iowa. Dashed lines are from analysis of the same samples in a nitrogen atmosphere to inhibit the masking reactions of organic matter.

rather unique for two reasons: The dusts are derived mainly from topsoils; and the dusts are usually picked up by abnormally strong winds, since strong winds are necessary to erode the topsoil. The dusts therefore contain significant amounts of organic matter and silt-size aggregates of clay, and because of the high winds, the dusts probably blow higher and farther than they would under ordinary conditions.

Figure 13 shows particle-size curves for a variety of C horizon Wisconsin loess samples in Iowa and for the dust which settled in Dodge City, Kansas. There is general agreement in that all curves show a break at about 50 mcirons. This break in the curve for the dust sample indicates the maximum-size particle easily carried in suspension, and many of the dust particles are close to this size. The remarkably good sorting in the silt-size range is not in accordance with the large amount of clay present in the dust. Considering that the clay was deposited partly as aggregates, as suggested above and confirmed under the microscope, the effect of topsoil aggregates is to increase the clay and decrease the silt contents measured after dispersion. Corrected for this effect, the particle-size curve of the dust would be closer to those for loess. Clay found as coatings would further modify the curves, but this is equally true for both the dust and the loess.

CONCLUSION

A number of relationships are demonstrated by this study:

1. Dust blowing from a source is approximately equal in particle-size to the source material minus the sand.

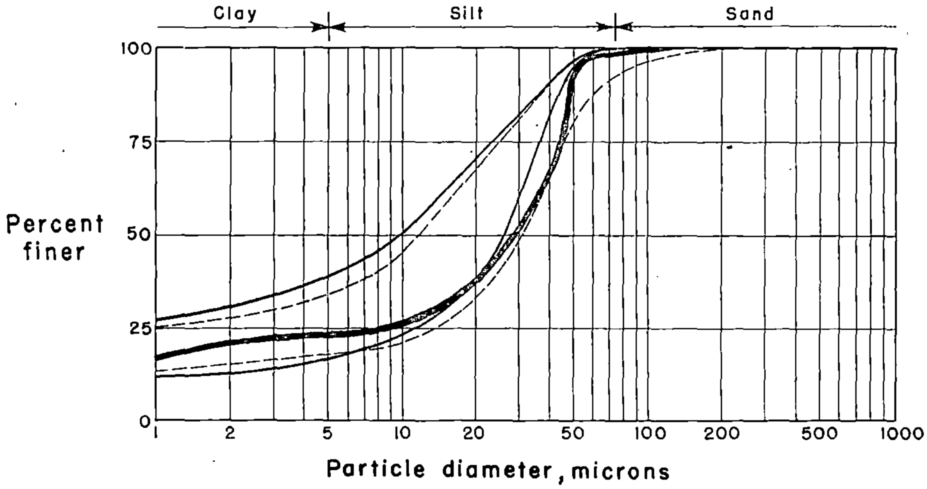

Fig. 13. The heavy line indicates particle sizes of dust which settled in Garden City, Kansas. Other particle-size curves are for Wisconsin age loess in Iowa. The solid lines are for typical samples from southwestern Iowa, the dashed lines typical samples from east-central Iowa.

2. A decrease in wind velocity results in settling out of the dust, particularly the coarser sizes.
3. Dust blown hundreds of miles becomes progressively finer because of settling out of the coarser materials.
4. Sand drifts in the Dust Bowl Area are made up of sand and sand-size aggregates of topsoil. A comparison of a drift sand with the topsoil source shows a considerable loss of silt and clay, presumably as dust.
5. Particle-size curves for dust near the source differ from those for loess near the alleged source of the loess. The difference is in the silt and clay ranges, and may be due to clay aggregates in the dust.

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   63: 53-55, 113-115, 148-175. 1935.
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PROPERTY VARIATIONS IN THE PEORIAN (WISCONSIN) LOESS OF SOUTHWESTERN IOWA

by

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R. L. Handy, Associate Professor, Civil Engineering

(Iowa Academy of Science Proceedings 59:248-265. 1952)

The Peorian loess in the southwestern Iowa area forms a massive surface deposit which mantles older (pre-Wisconsin) loesses and glacial deposits. This loess is believed to have accumulated during and immediately following glaciations of the Wisconsin glacial age which invaded northern Iowa and Nebraska. Four glacial drifts of Wisconsinian age, the Iowa, Tazewell, Cary, and Mankato, have recently been mapped in northwestern Iowa. Most geologists now agree that the Peorian loess in southwestern Iowa was deposited by the wind. Sources of the loess are thought to be the flood plains of the major outwash carrying valleys of the region; some of the loess also appears to have been blown directly from the drift surfaces in northwestern Iowa.

The topography within the boundaries shown in figure 1 has been described [11, 18] as loess depositional and loess mantled erosional. The principal soil association areas are the Monona-Ida-Hamburg and the Marshall[15].

In connection with the study of areal and stratigraphic variation of phy-

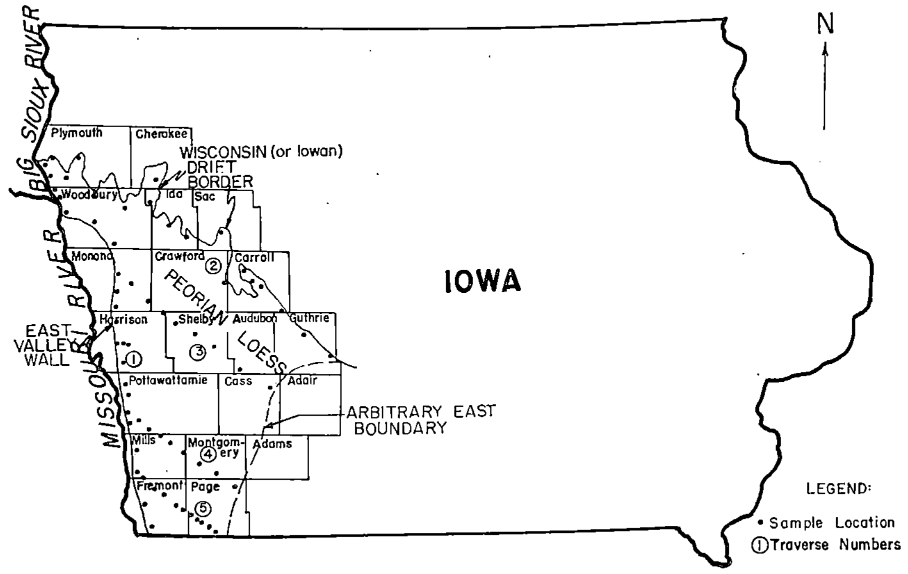

Fig. 1. Locations of sampling traverses in Peorian loess of southwestern Iowa.

sical and chemical properties of the loess, over one hundred samples have been taken along five traverses (figure 1). Control sampling was done on ridges or hilltops at each of the locations shown on the map. Since the thickness of the surface soil (solum) varied from zero or a few inches at the west boundary (east valley wall of the Missouri River) to a maximum of three or four feet near the arbitrary east boundary, control samples for determining areal property variations were taken to represent the loess parent material at a depth of between two and three feet below the top of the C horizon. Additional deeper samples were obtained at many of the locations for the purposes of the stratigraphic variation study. A 6 inch diameter soil auger was used for securing samples when suitable road cuts could not be found.

The physical and chemical property data were obtained by means of the following test methods:

1. Air-dry color (Munsell soil color charts for soil scientists, geologists, and archaeologists).
2. In-place (field) density (rubber balloon method)[6].
3. Field moisture content[6].
4. Mechanical analysis (A.S.T.M. Method: D422-51 as modified by Davidson and Chu[4]).
5. Plasticity index (A.S.T.M. Method: D424-39).
6. Shrinkage limit (A.S.T.M. Method: D427-39).
7. Centrifuge moisture equivalent (A.S.T.M. Method: D425-39).
8. Specific gravity (A.S.T.M. Method: D854-50T).
9. Textural classification (Bureau of Public Road System)[20].
10. Engineering classification (revised Bureau of Public Roads System)[1].
11. Carbonate content, expressed as percent $CaCO_3$ (rapid titration method)[14].
12. pH (hydrogen ion meter).
13. Organic matter content (dichromate oxidation method)[3].
14. Cation exchange capacity (ammonium acetate method)[5].
15. Differential thermal analysis (method described by Hauth and Davidson)[7].

PROPERTY VARIATIONS ALONG TRAVERSE 3

In a study of surface soils derived from Peorian loess in southwestern Iowa, depth measurements of the loess were made along traverse 3 (Hutton's traverse 1)[6, 10]. The traverse begins at the east valley wall adjacent to the wide Missouri River flood plain in Monona County and extends in a southeasterly direction to an arbitrary east boundary, approximately eighty miles away. The direction of the traverse was laid out at right angles to the direction in which the dune-type bluffs extend in the area of the traverse origin and is believed to represent with a reasonable degree of accuracy the direction of the generally prevailing winds during loess deposition time[13].

Table I presents the locations of samples obtained along the traverse. The soil series at the location from which each sample was taken is also shown.

TABLE I. SAMPLE LOCATIONS ALONG TRAVERSE 3.

Sample No.	Dist. from East Valley Wall, miles	Sampling[a] Depth, ft.	County	Location Section	Township North	Range West	Soil Series
22-1	0	2-3	Monona	NW¼,SE¼,S-8	84	44	Hamburg
23-1	9.8	2-3	Monona	SE¼,SE¼,S-9	83	43	Ida
24-1	20.0	2-3	Monona	SE¼,SW¼,S-14	82	42	Ida
24-2	20.0	29-30	Monona	SE¼,SW¼,S-14	82	42	Ida
25-1	27.0	2-3	Harrison	NE¼,NW¼,S-2	81	41	Monona
25-2	27.0	7.5-8.5	Harrison	NE¼,NW¼,S-2	81	41	Monona
26-1	32.7	2-3	Shelby	SW¼,SE¼,S-21	81	40	Monona(?)
26-2	32.7	8-9	Shelby	SW¼,SE¼,S-21	81	40	Monona(?)
27-1	44.0	2-3	Shelby	SW¼,SE¼,S-25	80	39	Marshall
28-1	55.3	2-3	Shelby	NW¼,NW¼,S-13	79	37	Marshall
29-1	66.6	2-3	Audubon	NW¼,SW¼,S-13	78	36	Marshall
30-1	78.2	2-3	Cass	SW¼,NW¼,S-21	77	34	Marshall

[a] Measurements are from top of C-horizon.

Depth Measurements.

Depth measurements of the Peorian loess along traverse 3 (figure 2) show the relationship between depth of the loess and distance from the east valley wall, which marks the edge of the Missouri River flood plain, thought to be the major source of the loess. The measurements, with the exception of the one at the traverse origin, represent the vertical distance from the earth's surface to the bottom of the Peorian loess deposit[12]. Since the measurements were made on ridges and hilltops where the loess is deepest, the data plotted in the graph show the variation in maximum thickness of the loess along traverse 3. The trend of the data appears to demonstrate the same phenomena of wind deposition previously found for similar traverses in the Peorian loess in Illinois[12, 17]. As previously mentioned, the solum thickness varied from zero to a few inches in the Hamburg soil series at the west end of the traverse to between 3 and 4 ft. in the Marshall series at the east end.

In-Place Properties.

As summarized in table II the air-dry Munsell color of the control samples, sampled 2 to 3 ft. below the top of the C horizon, is pale yellow, light yellow brown or light olive brown. All are oxidized. The samples taken at greater depths exhibit the same colors with the exception of one oxidized sample (26-2), which is light gray. Each of the other depth samples is oxidized, although there may be occasional streaks or mottles of gray. The gray unoxidized loess is much more common toward the eastern end

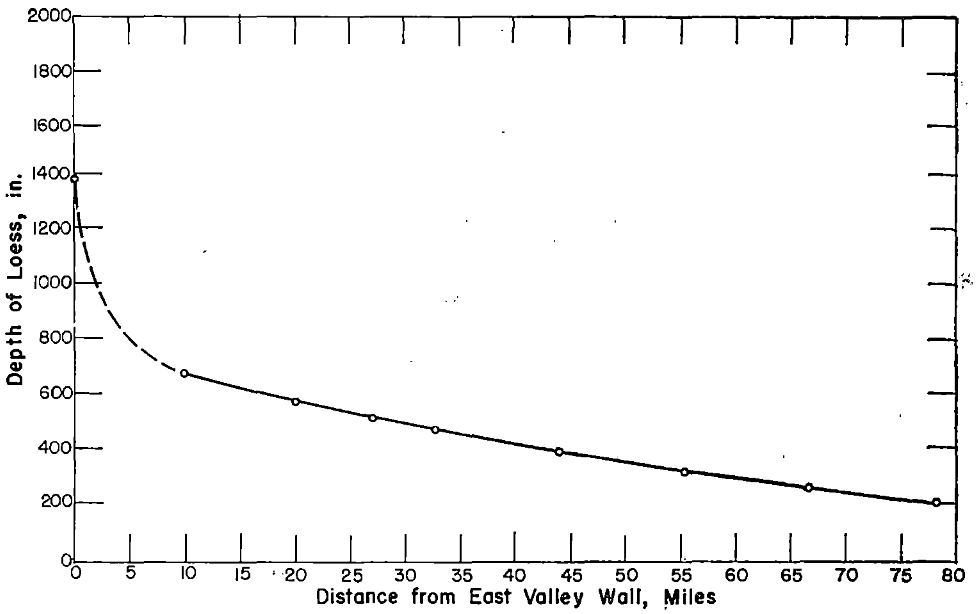

Fig. 2. Variation in maximum thickness of Peorian loess along traverse 3.

Table II. In-Place Properties of Peorian Loess Along Traverse 3

Sample No.	Dist. from East Valley Wall, miles	Sampling Depth[a], ft.	Air-Dry Munsell Color	Oxidation	In-Place (Field) density[b] lb./cu. ft.	Field Moisture Content[b], %
22-1	0	2-3	Lt. yel. br.	Oxidized	69.4	6.8
23-1	9.8	2-3	Pale yel.	Oxidized		
24-1	20.0	2-3	Lt. yel. br.	Oxidized	73.5	13.8
24-2	20.0	29-30	Pale yel.	Oxidized	89.5	20.8
25-1	27.0	2-3	Lt. yel. br.	Oxidized		
25-2	27.0	7.5-8.5	Lt. yel. br.	Oxidized		
26-1	32.7	2-3	Pale yel.	Oxidized	76.2	22.9
26-2	32.7	8-9	Lt. grey	Unoxidized	87.4	25.5
27-1	44.0	2-3	Lt. yel. br.	Oxidized		
28-1	55.3	2-3	Lt. olive br.	Oxidized	79.6	27.7
29-1	66.6	2-3	Pale yel.	Oxidized		
30-1	78.2	2-3	Pale yel.	Oxidized	83.5	28.0

[a] Measurements are from top of C-horizon.

[b] Field tests made September 7, 1951. Density determinations are in terms of oven-dry weights. Moisture contents are expressed as percentages of oven-dry weight of the soil.

Table III. Engineering Properties of Peorian Loess along Traverse 3

Sample No.	Dist. from East Valley Wall, miles	Sampling Depth[a], ft.	Physical Test Values: Plasticity Index, %[b]	Shrinkage Limit, %[b]	Centrifuge Moisture Equivalent %[b]	Specific Gravity 25°C/40°C	B.P.R.[c] Classification: Textural	Engineering
22-1	0	2-3	5.7	24.7	11.7	2.70	Silty Loam	A-4(8)
23-1	9.8	2-3	5.3	24.2	14.8	2.71	Silty Loam	A-4(8)
24-1	20.0	2-3	5.2	22.4	19.3	2.71	Silty Clay Loam	A-4(8)
24-2	20.0	29-30	5.5	22.1	20.0	2.71	Silty Clay Loam	A-4(8)
25-1	27.0	2-3	14.4	22.3	20.1	2.71	Silty Clay Loam	A-6(10)
25-2	27.0	7.5-8.5	12.1	22.4	18.9	2.70	Silty Clay Loam	A-6(9)
26-1	32.7	2-3	12.5	23.3	19.5	2.70	Silty Clay Loam	A-6(9)
26-2	32.7	8-9	17.8	21.9	21.6	2.69	Silty Clay Loam	A-6(9)
27-1	44.0	2-3	18.2	21.3	22.1	2.70	Silty Clay	A-7-6(12)
28-1	55.3	2-3	16.2	22.0	20.8	2.70	Silty Clay Loam	A-6(10)
29-1	66.6	2-3	18.0	18.9	21.5	2.70	Silty Clay	A-6(11)
30-1	78.2	2-3	26.6	17.8	25.4	2.70	Silty Clay	A-7-6(16)

[a] Measurements are from top of C-horizon.

[b] Percent of oven-dry weight of the soil.

[c] Bureau of Public Roads.

of the traverse, and is, in fact, unobserved at the west end. The depth of oxidation may be a measure of the permeability to aqueous solutions[8]. The centrifuge moisture equivalent data of the present study (table III) indicate that the loess becomes less permeable with increasing distance from the traverse origin. The depth of oxidation was observed to be shallower on hillsides, possibly due to less infiltration of surface water[16].

Root tubles, or decayed roots, noted at several sample locations, are especially noticeable in the unoxidized loess and in the transition zone into the oxidized material above. The root tubules appear to be concentrations of iron oxide around old root channels. They are usually vertical and frequently up to one-half inch in diameter. Secondary line concretions, where present in the samples taken along traverse 3, are small and few in number.

The in-place (field) density of the loess was measured at five sampling locations (table II) along the traverse. There is a linear increase of in-place density with distance from the east valley wall (figure 3). The data also indicate that this property increases with depth in the loess.

Field moisture contents were determined at the same time (September 7, 1951) that the field density measurements were made. There had been no recent rainfall reported in the vicinity of the traverse. The data (table II and figure 3) indicate that the moisture holding capacity of the loess increases both with depth and with distance from the valley wall.

Texture.

Mechanical analyses of the silt and clay fractions of the loess were made

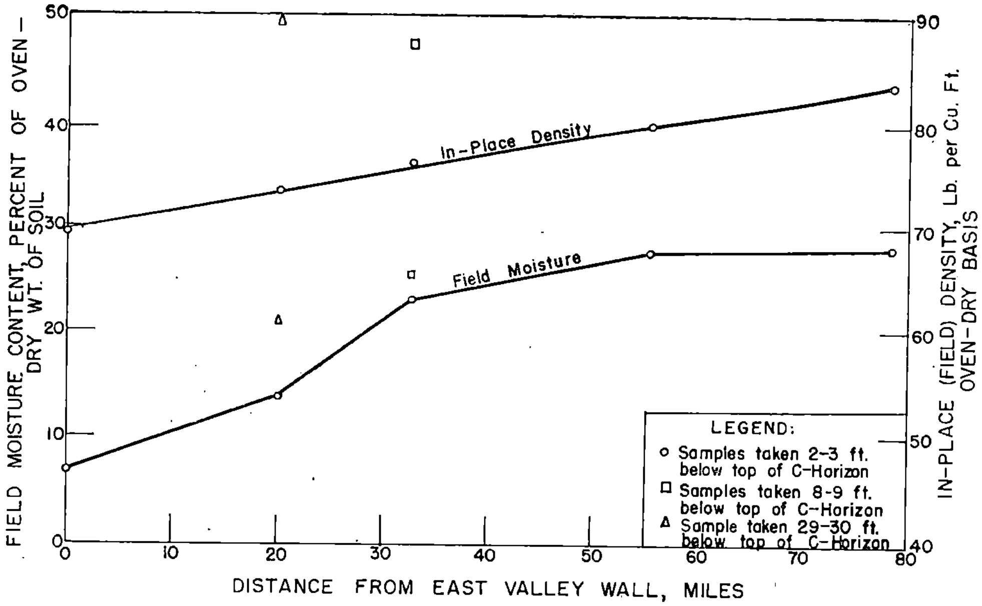

Fig. 3. Variation in field moisture content and in-place density of Peorian loess along traverse 3.

by the modified hydrometer method[4]. Sodium metaphosphate was used as the dispersing agent. The sand fraction was separated by mechanical sieving.

The texture of the loess ranges from silty loam near the valley of the Missouri River through silty clay loam to silty clay toward the east end of the traverse (table III). Particle-size accumulation curves for the samples which are lowest (Sample 22-1) and highest (Sample 30-1) in clay content are presented in figure 4.

The textural composition of the loess and distance from the valley wall are related (figure 5). The sand content, including small lime concretions, is low and practically uniform. The clay content increases, and the silt content decreases with increasing distance from the traverse origin.

The decrease in median particle size can be seen (figure 5). Similar trends in the Peorian loess have been reported in Iowa [10, 11], in Illinois[17], and in Kansas[19]. On the basis of the data presented, the variation in textural composition is not large or consistent with depth.

Hillside Texture Variation. As previously explained, the control samples were taken on ridges or hilltops at the depth of two to three feet below

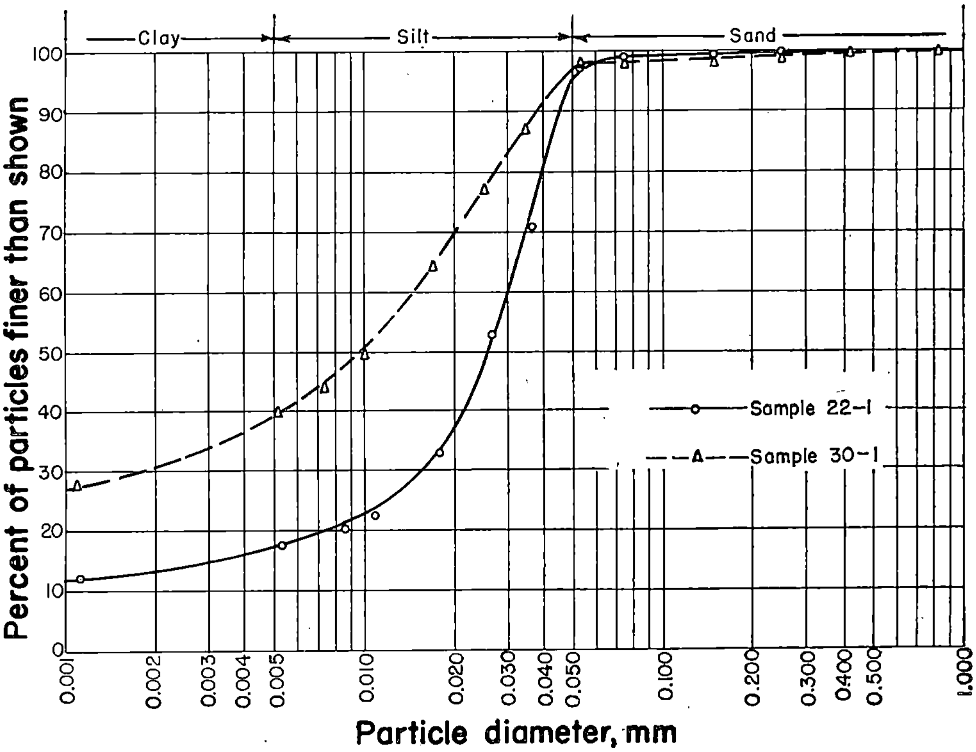

Fig. 4. Particle-size accumulation curves for samples obtained at west (22-1) and east (30-1) ends of traverse 3.

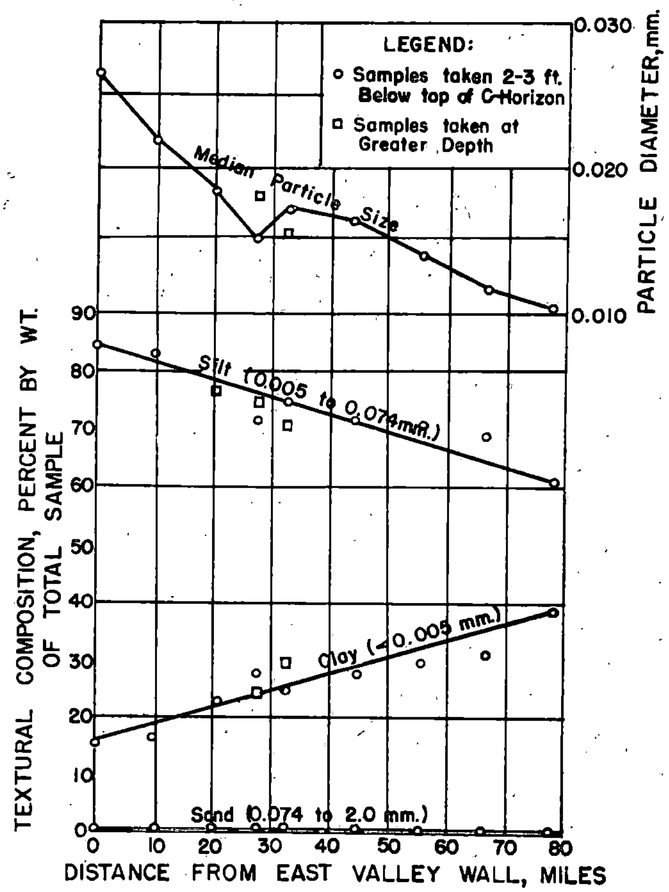

Fig. 5. Variation in particle size of Peorian loess along traverse 3.

the top of the C-horizon. To determine local variations in texture of the loess, hillside samples were also taken down the slope from each of the control locations. These samples were taken on either east and west or north and south hillsides. On those slopes of over 100 feet in length two samples were taken, one approximately half way down the slope and the other near the base. On shorter slopes, sampling was done only near the base. The sampling depth for hillside samples was the same as for the control samples. Due to the lack of stratification in the loess it was impossible to sample consistently from the same strata.

The variation in median particle diameter between each hillside sample and its hilltop control sample shows no consistent trend towards a coarser or finer particle size in any direction downhill (figure 6). Also, the hillside variations appear to be about the same as the stratigraphic

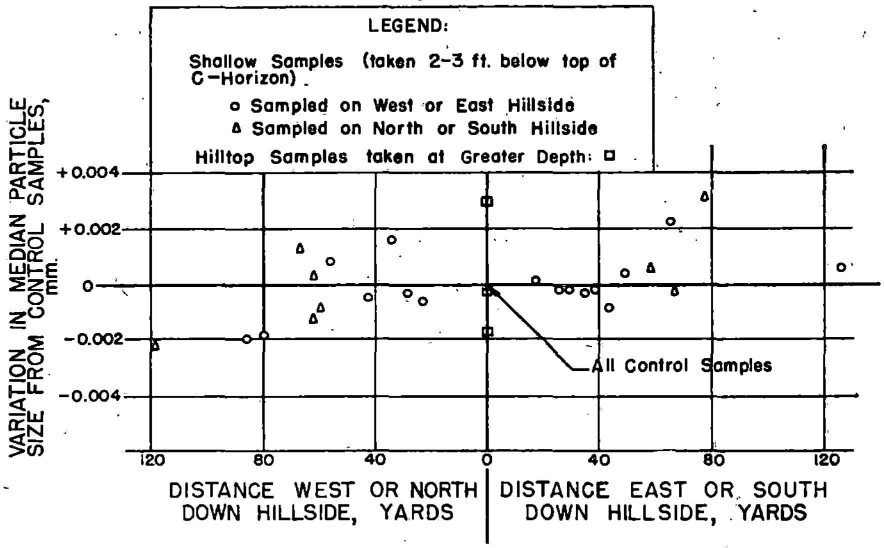

Fig. 6. Variations in medium particle size of hillside samples from the control (shallow hilltop) samples.

variations. Particle-size accumulation curves for the hillside samples are practically identical with those of the control samples.

Engineering Properties.

Table III presents data showing the variation in some physical properties commonly used to predict the behavior characteristics of engineering soils[2, 9, 22]. The trends of the plasticity index, shrinkage limit, and centrifuge moisture equivalent data reflect a marked increase in plasticity, shrinkage and resistance to flow of water in the loess with increasing distance southeast along traverse 3. The stratigraphic variation of these properties is small and shows no significant trend. The true or absolute specific gravity of the Peorian loess is quite uniform throughout the traverse.

The sharp increase in the plasticity index of the loess (figure 7) between sampling locations 20 and 27 miles southeast of the traverse origin approximates the location of the gradational east boundary of the region of high bluffs[11]. The change in the B.P.R. engineering classification of the loess (table III) from group A-4 to group A-6 between the same sampling locations indicates a significant change in engineering properties. The A-4 group includes friable, silty soils which wet readily, even without manipulation, and lose stability, and are extremely subject to frost action. The A-6 group includes more plastic, clayey soils which wet slowly unless manipulated. When wet, A-6 soils dry more slowly than A-4 soils. The A-6 soils are subject to mud-pumping under Portland cement concrete pavement slabs but, in general, are not subject to detrimental frost action.

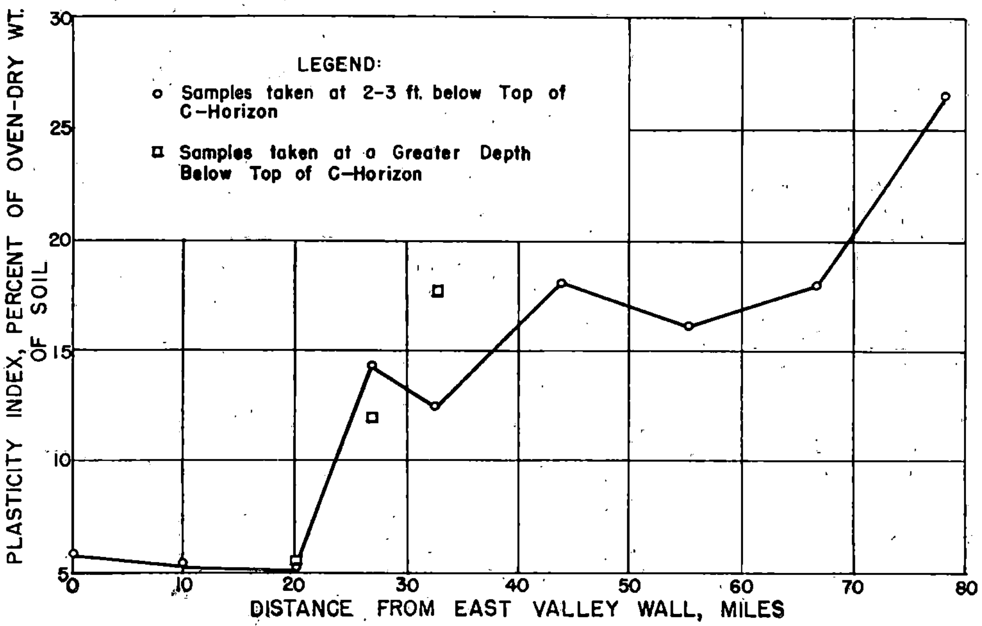

Fig. 7. Variation in plasticity index of Peorian loess along traverse 3.

The change from the A-6 group to the A-7 group (A-7-6 subgroup) reflects the increasing clay content of the loess towards the east end of the traverse. Soils classified as A-7-6 possess the behavior characteristics of A-6 soils, but are more subject to shrinkage and swelling.

Chemical Properties.

Some chemical properties of the Peorian loess vary along the traverse (table IV). The carbonate content, expressed as present $CaCO_3$, is highest at the valley wall, immediately adjacent to the river flood plain. Carbonate

TABLE IV. CHEMICAL PROPERTIES OF PEORIAN LOESS ALONG TRAVERSE 3

Sample No.	Dist. from East Valley Wall, miles	Sampling Depth[a], ft.	Carbonate Content, %[b] $CaCO_3$	pH	Matter Organic Content, %[b]	Cation Exchange Capacity, m.e./100g[c]
22-1	0	2-3	15.0	8.6	0.30	10.4
23-1	9.8	2-3	12.3	8.6	0.22	14.7
24-1	20.0	2-3	11.8	8.4	0.34	14.3
24-2	20.0	29-30	9.8	8.6	0.16	14.6
25-1	27.0	2-3	12.6	8.3	0.40	15.5
25-2	27.0	7.5-8.5	10.0	8.3	0.20	15.7
26-1	32.7	2-3	1.4	7.0	0.18	18.2
26-2	32.7	8-9	8.7	8.3	0.17	17.9
27-1	44.0	2-3	1.5	7.0	0.16	19.3
28-1	55.3	2-3	7.6	8.4	0.21	17.6
29-1	66.6	2-3	2.9	8.3	0.25	19.5
30-1	78.2	2-3	1.6	6.9	0.21	20.4

[a] Measurements are from top of C-horizon.
[b] Percent of oven-dry weight of the entire soil fraction.
[c] Milliequivalents per 100 g. of oven-dry soil.

percentages, however, are high throughout the western third of the traverse, where there is little evidence of leaching in the C horizon. As seen from the data, leaching of the upper C horizon is greater along the remainder of the traverse. The pH values of the unleached loess samples are quite uniform, varying from 8.3 to 8.6. The leached samples have a pH near 7. The organic matter content of the loess below the top of the C horizon is low throughout the traverse. The data indicate a slight decrease of organic matter with depth.

The increase in cation exchange capacity of the whole soil material with distance away from the valley wall chiefly reflects the increase in the amount of clay in the loess (table IV, figure 8). The data show no appreciable variation of this property with depth.

Thermal Curves

The differential thermal method of analysis is a rapid, relatively accurate method of analyzing soils qualitatively for certain constituents, particularly the clay minerals[7]. The thermal curves for alternate samples along the traverse represent the entire loess fraction without any pre-treatment (figure 9). The presence of quartz in all samples is denoted by the nipple-like peak at about 573°C, protruding from the endothermic reaction. The prominent endothermic reaction between 800° and 900° C shows the high carbonate content of the unleached samples (samples 22-1, 24-1, 24-2, 26-2,

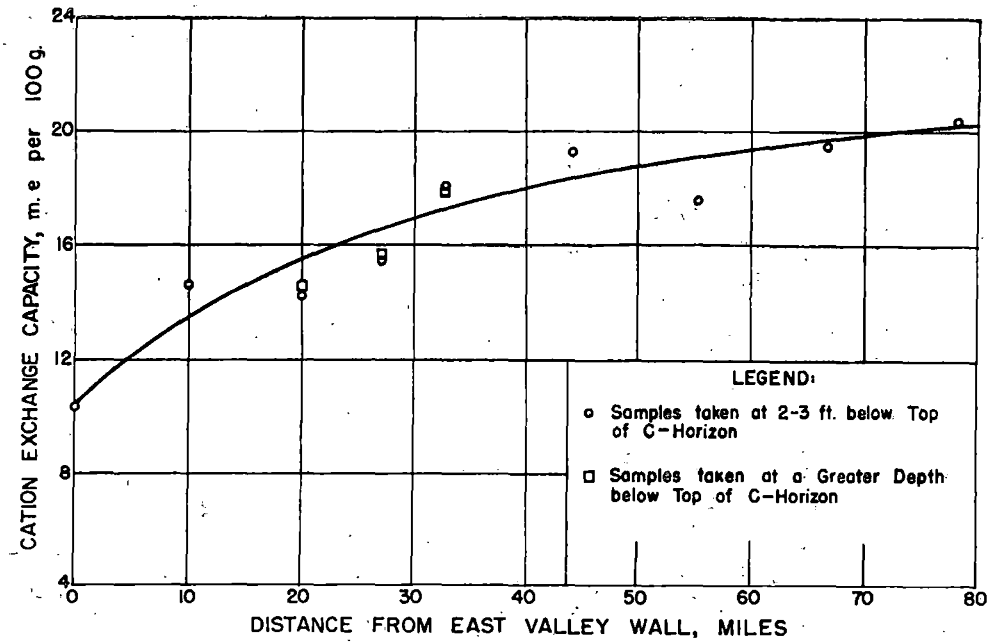

Fig. 8. Variation in cation exchange capacity of Peorian loess along traverse 3.

and 28-1). The size of the reaction indicates qualitatively the relative amount of carbonate.

Thermal patterns for montmorillonite and illite group clay minerals are

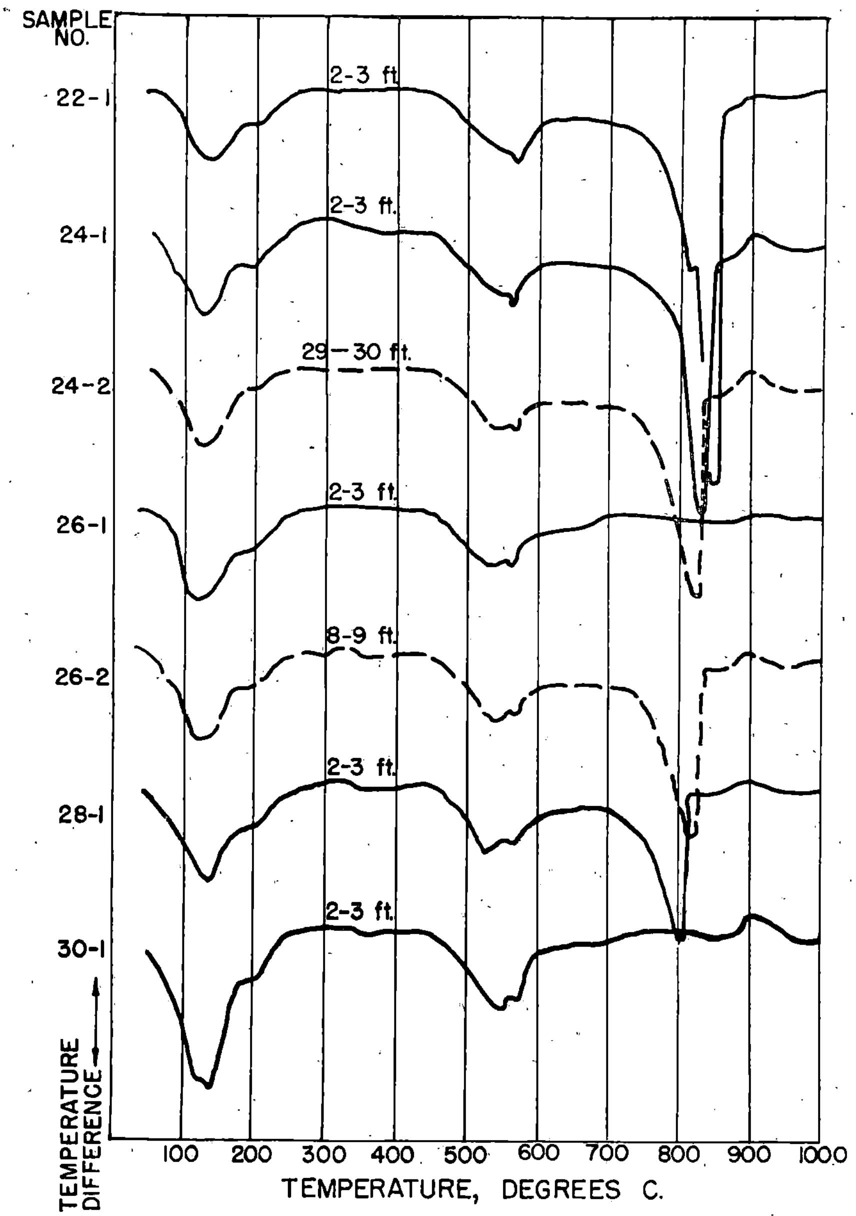

Fig. 9. Thermal curves of alternate samples along traverse 3. Sampling depth below top of C horizon is shown on curves.

quite similar, both minerals giving three endothermic reactions and one exothermic. Only the second endothermic reaction may be used for identification. This occurs between 500° and 600° C in the case of illites, and between 600° and 700° C for the montmorillonites. In all samples the second endothermic reaction occurs in the temperature range 500° to 600° C, indicating that illite-type minerals are predominant in the clay fraction. A predominance of montmorillonite-type clay minerals has been reported in loess (presumably Peorian) samples from Trenton Dam, Missouri River Basin Project in Nebraska[21].

CONCLUSIONS

The following conclusions apply to the Peorian loess along traverse 3 in southwestern Iowa (figure 1):

1. The air-dry Munsell color of the oxidized Peorian loess along the traverse is pale yellow, light yellow brown or light olive brown. The unoxidized loess where sampled is light gray.

2. The in-place density of the loess appears to increase linearly with increasing distance from the east valley wall of the Missouri River. It also increases with depth.

3. The field moisture content of the loess increases in general with depth and with distance from the east valley wall.

4. The loess along the traverse is predominantly silt. The clay content increases, and the silt content and median particle diameter decrease with distance southeast along the traverse. The sand content is uniformly low. There is no large or consistent variation in texture with depth.

5. The median particle diameter of the loess does not show any large or consistent variation with distance or direction down hillsides from hilltop control locations.

6. Plasticity, shrinkage, and resistance to flow of water increase in the loess with distance southeast from the traverse origin. The stratigraphic variation of these properties is small and shows no significant trend.

7. The true specific gravity of the loess is quite uniform throughout the traverse.

8. The carbonate content is high in the loess throughout the western third of the traverse. Leaching of the upper C horizon is more prominent along the remainder of the traverse.

9. The pH values of unleached loess vary from 8.3 to 8.6; the pH of leached loess is near 7.

10. The organic matter content of the loess below the top of the C horizon is low throughout the traverse.

11. The cation exchange capacity of the loess increases with distance away from the valley wall; the data show no appreciable variation with depth.

12. The clay-mineral composition of the Peorian loess along the traverse appears to be uniform. Studies to date indicate that minerals of the illite group predominate.

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DEPTH STUDIES OF THE WISCONSIN LOESS IN SOUTH-WESTERN IOWA: PARTICLE SIZE AND IN-PLACE DENSITY

by

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(Iowa Academy of Science Proceedings 60:333-353. 1953.)

As an aid in selecting loess sections for detailed sampling, the southwestern Iowa loess area was divided into three sub-areas on the basis of the Bureau of Public Roads classification system[2]. The liquid limit, plasticity index, and particle-size data necessary for this classification were obtained from over 100 samples of Wisconsin loess taken along five traverses (figure 1). Most of these samples were taken from the upper C-horizon. The A-4 group includes friable, silty soils, and the A-6 group includes more plastic, clayey soils. Soils in the A-7-6 sub-group (A-7 group) are even more plastic and clayey. The A-4 loess area coincides approximately with the area of deep-loess topography bordering the Missouri River floodplain.

Sections for detailed depth sampling (figure 1) were chosen to be representative of each of the three sub-areas. Because of the amount of loess in the A-4 area and the low agricultural value of the land, this is a potentially important source of road-building material, and for this reason four sections (1, 2, 3 and 4) (figure 1) were studied. Of these, three are in the first bluff line east of the Missouri River flood plain. The Pisgah section (3 in figure 1) in the A-4 area was selected to compare a section of Cary-Mankato or Upper Wisconsin loess with the undifferentiated Wisconsin loess in other sections. A section near Soldier (4 in figure 1) was chosen to represent A-4 loess near the transition to the A-6. The A-6 loess is represented by a section near Harlan (5 in figure 1), the A-7-6 by a section near Red Oak (6 in figure 1). An additional A-7-6 loess section adjacent to the Mankato lobe of the Wisconsin glaciation near Redfield (7 in figure 1) was studied because of the extent of the A-7-6 area and for comparison with data from an eastern Iowa loess study now under way.

METHODS OF SAMPLING AND TESTING

For the most part in the deep loess section sampling and in-place density measurements were conducted from a rope swing equipped with a 3-to-1 block and tackle arrangement. This was suspended from a collapsible aluminum beam anchored at the back by a cork-screw type soil anchor (figures 2 and 3). Where necessary, augering was employed in sampling. Shallower loess section could be studied without the use of ropes (figure 4).

On old cuts the exposed face of the section was cut back a distance of about two feet before samples were taken or density determinations were made.

In-place density tests were conducted with a modified rubber-balloon apparatus designed for use on vertical or inclined faces. With this rubber-balloon apparatus (figures 4, 5) density measurements were made as follows:

A hole approximately 4 in. in diameter and 4 in. deep was dug in the soil and the material removed was weighed and sampled for a field moisture determination[4].

A balloon was forced into the hole by water from a vertical standpipe calibrated so that the volume of the hole could be read directly from the fall of the water level in the standpipe.

Previous types of rubber-balloon apparatus were found to be too bulky, heavy, and awkward to read, especially since their use is restricted to hori-

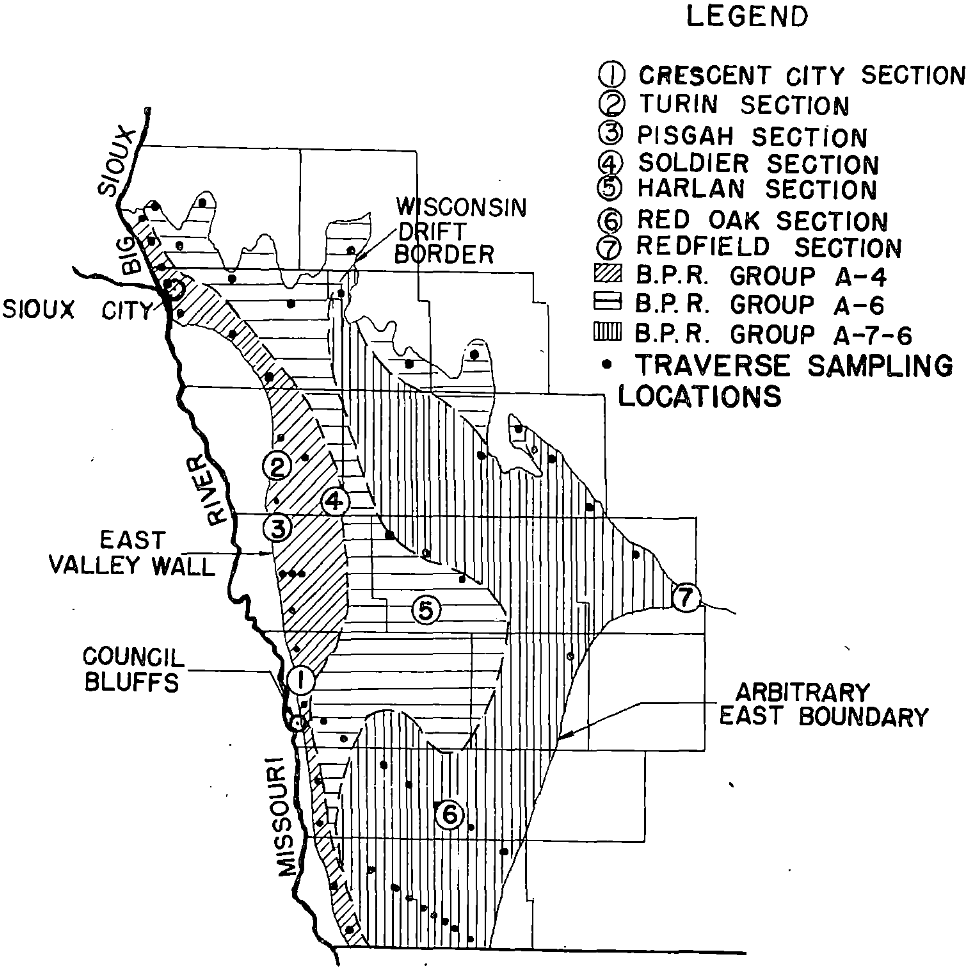

Fig. 1. Locations of depth sections in southwestern Iowa loess area.

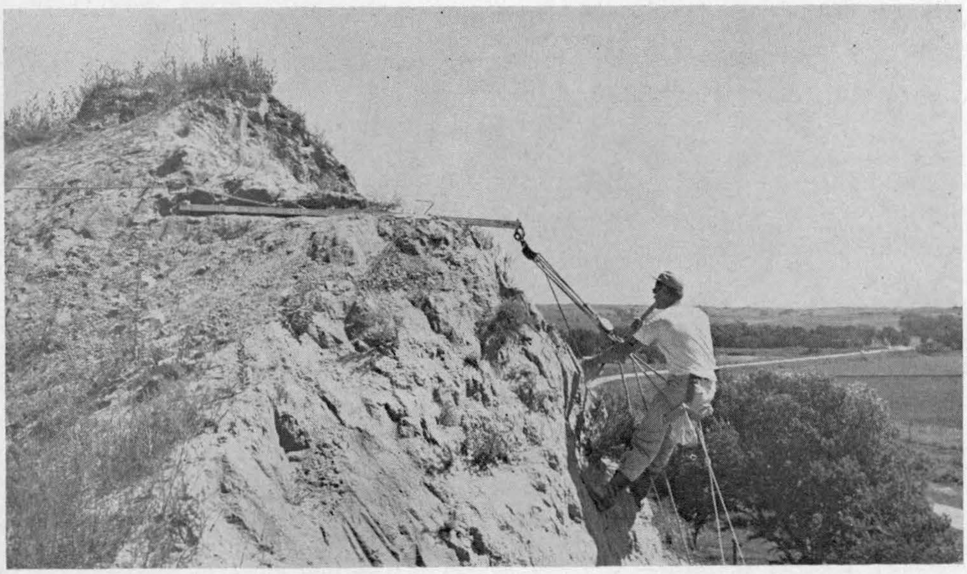

Fig. 2. Depth sampling at Turin. The suspension appartus was a block and tackle arrangement with an aluminum beam anchored by a cork-screw type soil auger.

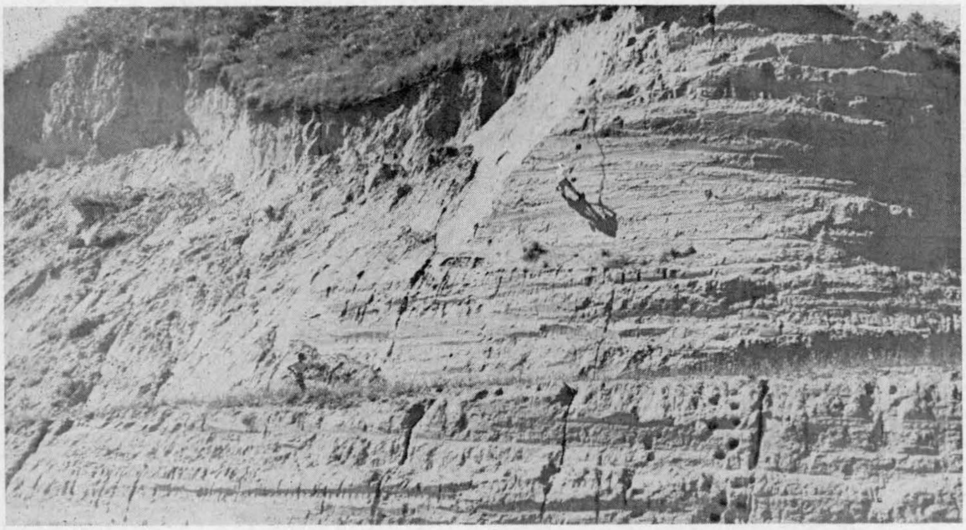

Fig. 3. Sampling the vertical face of the Crescent City section of deep loess. The Wisconsin loess was estimated to extend ten feet below the bottom of the cut. The top part of the section was sampled by augering horizontally into the hill.

zontal surfaces cut in the soil. Other in-place density methods used by engineers are more time-consuming, require more calculations, and are frequently less accurate[4] than the rubber-balloon-method.

Mechanical analyses of the silt and clay fractions of the samples were made by the standard American Society for Testing Materials hydrometer method D422-51 as modified[5]. Sodium metaphosphate was used as the dispersing agent. The sand fraction was separated by mechanical sieving.

RESULTS AND CONCLUSIONS

Particle-Size

Particle-size data for the seven loess sections are in Appendix B. In the Crescent City Section the sand content is low, averaging 3.2 percent, but increases with depth from 1 to almost 10 percent sand (figure 6). The clay content averages 16.5 percent and shows several broad general peaks at various depths. The textural variation of the loess in the Crescent City Section is probably negligible for engineering uses. No Brady soil[6] was detected in the field.

Fig. 4. In-place density determination in Red Oak section with rubber-balloon appartus. The test being made is at the bottom of the loess.

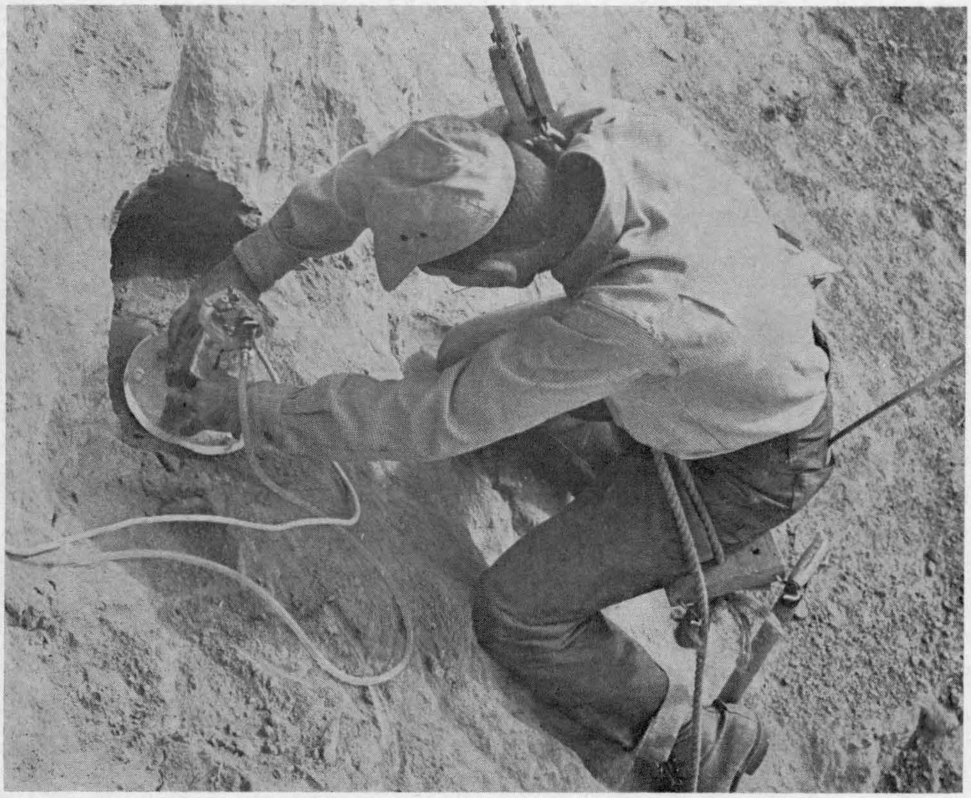

Fig. 5. In-place density determination at Turin with rubber-balloon apparatus.

From the histogram showing the distribution of the Crescent City loess samples with regard to their clay contents (figure 7) it can be seen that the largest number of samples are in the minimum clay content bar, and progressively fewer samples show higher clay contents. Identical trends were noted in histograms for the other A-4 sections at Turin and Soldier. Similar histograms for sand contents show a more nearly normal distribution. The skewed clay content distribution is probably related to the origin of the loess and might conceivably indicate lulls from a sustained maximum rate of deposition. If this is true, carbonate data not yet obtained may verify it, or migration of carbonates may have obliterated any trends. In the Crescent City Section four clay content peaks may be noted (figure 6) at approximate depths of 0, 25, 45 and 75 feet. The peaks divide the section into four units which may be related to the four divisions of the Wisconsin glaciation. Concretions near the bottom of the loess section prevented augering and sampling completely down to the contact.

In the Turin Section sampling was done at ten foot intervals instead of every five feet, so clay peaks may have been missed .Peaks occur at 40, 80 and 100 feet; the latter sample is at the base of the section. The top of the section has been removed by erosion and borrow operations. The clay and sand contents are fairly uniform from an engineering standpoint, averaging 15.3 and 1.9 percent, respectively.

In the Pisgah Section clay content peaks occur at the surface and in and above the Brady soil. Sampling was not continued from the Brady down through the lower Wisconsin loess because of slump. The clay content reaches a sharp peak in the Brady soil; the sand content drops abruptly above the Brady. For about two feet above the Brady soil the loess is gray and non-calcareous but contains a few snail shells. Above this it is calcareous. Below the Brady it is leached for about two feet.

Due to the steep slopes and the porous nature of the loess in the above bluff-line sections at Crescent City, Turin, and Pisgah, little or no soil profile development is at the surface. The surface soil is a lithosol of the Hamburg soil series.

In the Soldier Section, which represents inland A-4 loess, the loess is thinner, has more clay on the average and less sand than in the bluff-line sections. The sand and clay contents of the loess are remarkably uniform with depth, averaging 0.8 and 22.3 percent, respectively. The surface soil is a lithosol of the Ida series with a brown, calcareous A-horizon about one foot thick.

The Harlan Section, representing A-6 loess ,is much thinner than the A-4 loess sections. The clay content of the loess is higher, averaging 25.8 percent in the loess, and there is much soil profile development (Marshall

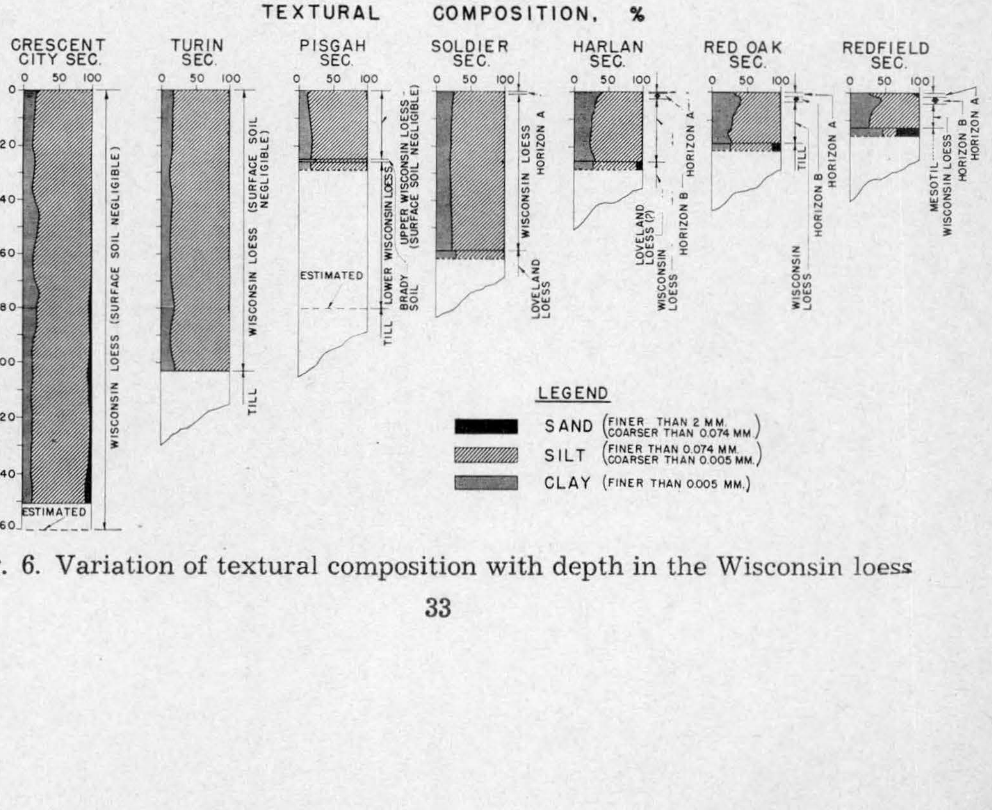

Fig. 6. Variation of textural composition with depth in the Wisconsin loess

series). Due to erosion the A-horizon is absent. The sand content is uniform and lower than other sections, averaging 0.7 percent. The first prominent leaching, to a depth of between five and seven feet, was noted in this section. There is a slight increase in clay in the lower three feet of the Wisconsin loess; this basal loess is unoxidized and leached.

The Red Oak Section is quite similar texturally to the Harlan Section but shows further increases in clay content and soil profile development (Marshall series) and a decrease in thickness. The entire section is leached, and all except the lower two feet is oxidized.

The Redfield Section is also leached throughout and shows a further in-

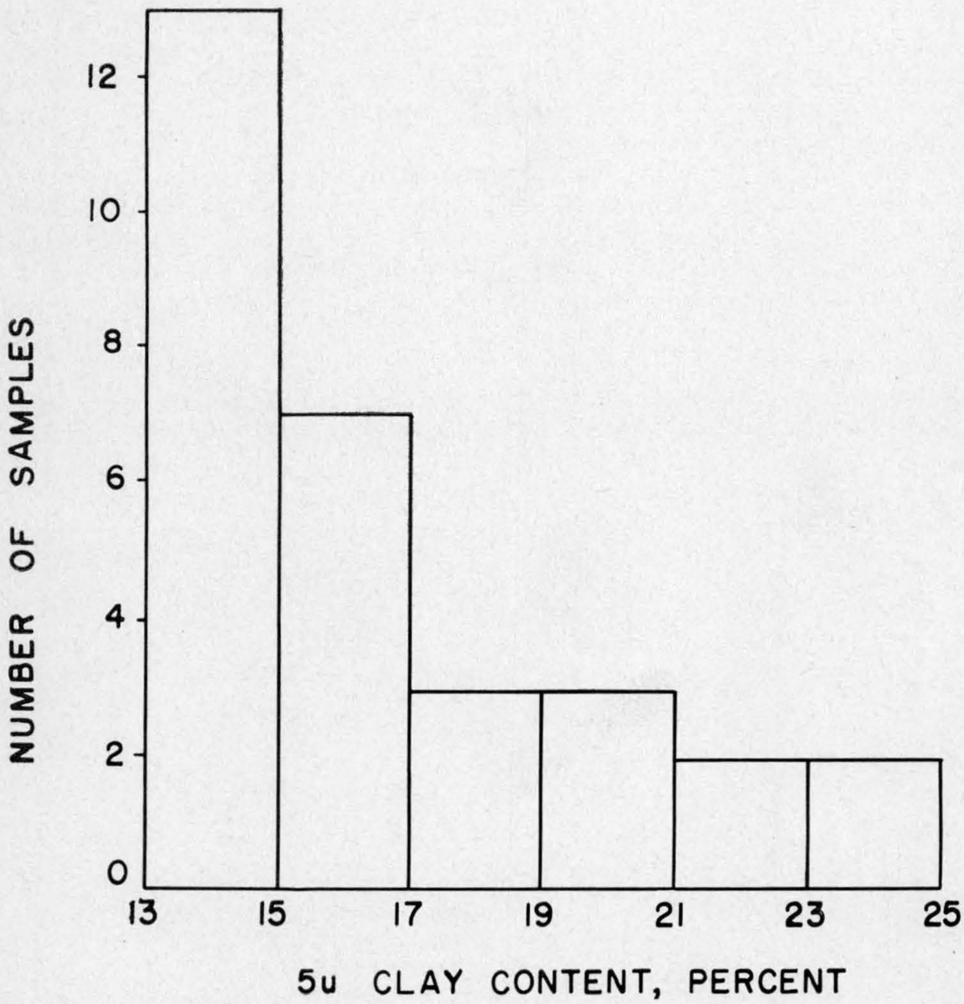

Fig. 7. Histogram showing clay content distribution of Crescent City section loess samples.

crease in clay content and an even greater dominance of the section by the soil profile (Sharpsburg series).

In the Harlan, Red Oak and Redfield sections the soil profile is transitional to the loess. Sand content in these sections are low and uniform but may

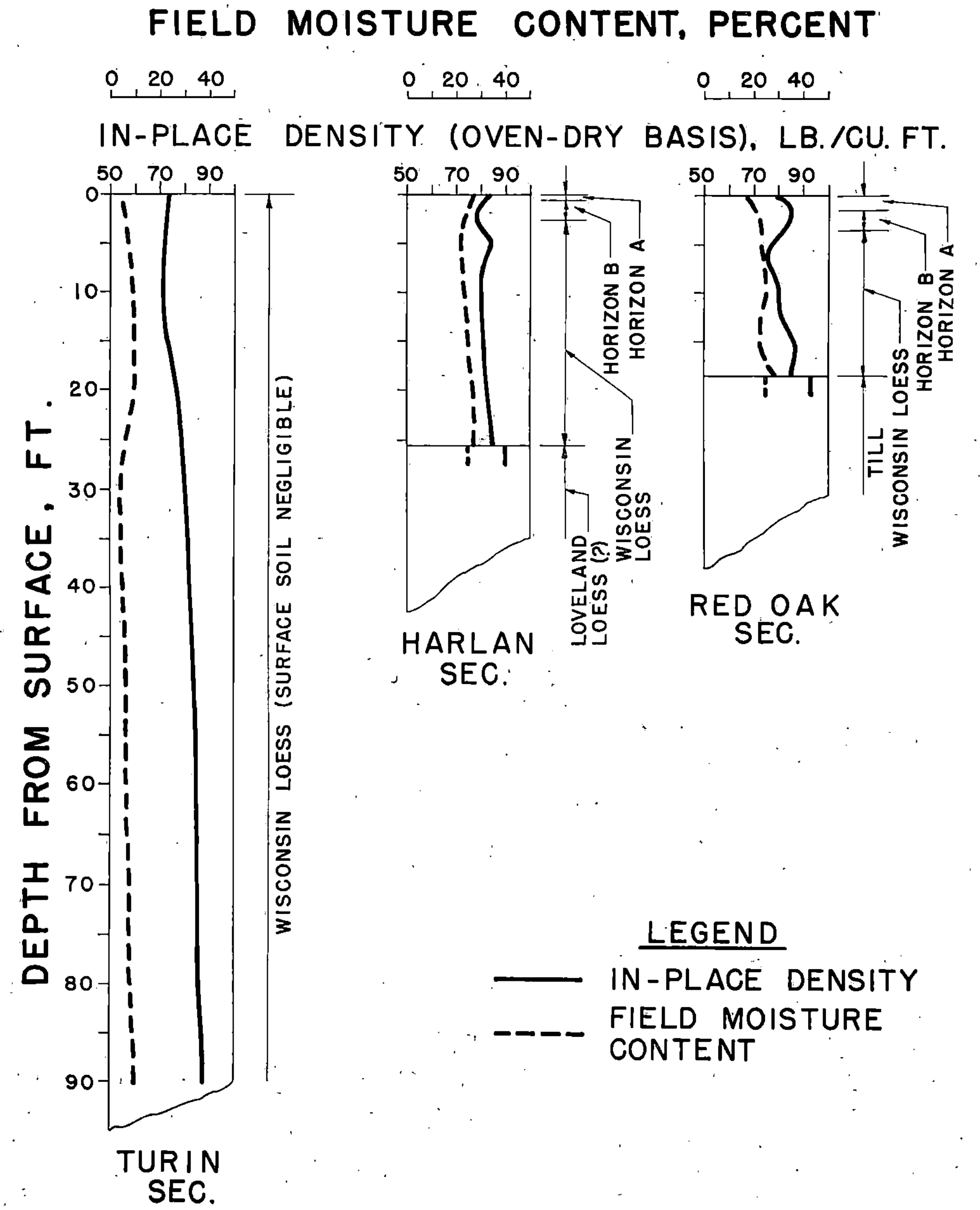

Fig. 8. Variation of in-place density and of field moisture content with depth in the Wisconsin loess.

show slight increases in the foot of loess immediately above the contact with old deposits. The presence of unoxidized layers at the bases of the Soldier, Harlan, Red Oak, and Redfield sections appears to be due to submergence below the water table and may be caused by deoxidation.

In-Place Density.

In-place density and field moisture measurements were made on October 25, 1952, September 19, 1952, and September 27, 1952, respectively in the Turin, Harlan, and Red Oak sections representative of the A-4, A-6, and A-7-6 loess areas. The density in all of these sections tended to increase with depth, due to consolidation from the load of the overlying material (figure 8). Anomalies in the Red Oak and Harlan sections may be explained by soil profile development and variations in moisture content. In these sections low moisture content was apparently related to high density. In the Red Oak section the density decreased just above the till, where the loess was saturated with water. In general the field moisture content increased with increasing depth and increasing clay content.

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Appendix A

Wisconsin Loess Sections, Southwestern Iowa

Crescent City Section*.—North face of quarry 1.5 mi. southwest of Crescent City, Pottawattamie County, Iowa. NW corner, Sec. 35, T. 76 N., R. 44 W.

Sample No.	Depth ft.	Method of Sampling	Material	Soil Series
1	0— ½	Augered at crest of hill	Loess. Coarse-textured, friable, calcareous, light buff in color. No Brady soil detected.	Hamburg. Lithosol, little soil profile development, calcareous to surface. No distinct A-horizon.
2	2— 2½	”	”	
3	5— 5½	Augered horizontally into hill down 41° slope.	”	
4	10— 10½	”	”	
5	15— 15½	”	”	
6	20— 20½	”	”	
7	25— 25½	”	”	
8	30— 30½	”	”	
9	35— 35½	”	”	
10	40— 40½	”	”	
11	45— 45½	”	”	
12	50— 50½	”	”	
13	60— 60½	Sampled down vertical face from ropes	”	
14	65— 65½	”	”	
15	70— 70½	”	”	
16	75— 75½	”	”	
17	80— 80½	”	”	
18	85— 85½	”	”	
19	90— 90½			
20	95— 95½	”	”	
21	100—100½	”	”	
22	105—105½	”	”	
23	110—110½	”	”	
24	115—115½	”	”	
25	120—120½	”	”	
26	125—125½	”	”	
27	135—135½	”	”	
28	140—140½	”	”	
29	145—145½	Augured	”	
30	150—150½	”	Concretion zone, large carbonate concretions. Augering stopped by concretions.	
—	160 (estimated)	No Sample		

* Since sampling (September, 1952) this section has been considerably modified by quarrying operations.

Pisgah Section.—Exposed face of bluff about 100 ft. south of County Road D, 4 mi. west of Pisgah, Harrison County, Iowa.
SW corner, SW¼, Sec. 8. T. 81 N., R. 44 W.

Sample No.	Depth ft.	Method of Sampling	Material	Soil Series
1	0 — ½	Sampled down slope	Loess, Upper Wisconsin. Coarse - textured, friable, calcareous, fossiliferous, light gray-buff in color.	Hamburg. No soil profile.
2	2½— 3	"	"	
3	14½— 15	"	"	
4	21 — 22	"	"	
5	23½— 24	"	Loess, Upper Wisconsin. Coarse-textured, friable, non-calcareous, fossiliferous, very light gray in color with rusty streaks. This zone is 2 ft. thick.	
6	25 — 25½	"	Brady soil. Leached, medium gray "buried soil" layer 12 to 16 in. thick. Organic layer at top contains minor amounts of charcoal.	
7	28 — 28½	"	Loess, Lower Wisconsin. Coarse-textured, friable, leached, light gray colored with rusty mottles.	
....	28½	No Sample.	Loess, Lower Wisconsin. Coarse-textured, friable, calcareous, fossiliferous, light gray-buff in color. Below this, slump.	
....	65	"	Concretion zone in loess.	
....	75	"	Slump.	
....	80 (estimated)	"	Till (exposed to west):	

Soldier Section.—North side of road cut on County Road M, 7 mi. southeast of Soldier, Monona County, Iowa. SW corner, SW¼, SE¼, Sec. 14, T. 82 N., R. 42 W.

Sample No.	Depth ft.	Method of Sampling	Material	Soil Series
1	0 — 1	Sampled from ropes down vertical face.	Soil, A-horizon. Brown, calcareous, silt loam.	Ida. Lithosol, little profile development, calcareous to surface.
2	1 — 2	"	Loess. Medium coarse-textured, friable, calcareous, buff-colored.	
3	3 — 3½	"	"	
4	10 —10½	"	"	
5	20 —20½	"	"	
6	30 —30½	"	"	
7	40 —40½	"	"	
8	50 —50½	Augered.	Loess. Slightly calcareous, buff-colored with gray mottles.	
9	58 —58½	"	Loess. Leached, buff-colored with red and yellow streaks.	
10	58½—59	"	Loveland Loess. Fine-textured, plastic, leached, medium gray-colored with red-brown mottles.	

Turin Section*.—Borrow Pit at Turin, Monona County, Iowa. NW corner, Sec. 10, T. 83 N. R. 44 W.

Sample No.	Depth ft.	Method of Sampling	Material	Soil Series
1†	0— ½	Augered from crest of knob back from face.	Loess. Coarse-textured, friable, calcareous, buff in color.	Hamburg. No soil profile.
2	2— 2½	"	"	
3†	10— 10½	Sampled from west side of knob.		
4†	20— 20½	"	"	
4a†	20— 20½	Sampled down vertical face from ropes.	"	
5†	30— 30½	"	"	
6†	40— 40½	"	"	
7†	50— 50½	"	"	
8†	60— 60½	"	"	
9†	70— 70½	"	"	
10†	80— 80½	"	"	
11†	90— 90½	"	"	
12	100—100½	Augered at base of cut.	"	
----	103—	Reached with auger. No sample.	Glacial till.	

* Since last sampling (October, 1952) this section has been modified by a slide.
† In-place density tests made.

Harlan Section.—North side of road cut on U. S. Hiway 64, 1 mi. east of Harlan, Shelby County, Iowa. SE¼, SW¼, Sec. 16, T. 79 N., R. 38 W.

Sample No.	Depth ft.	Method of Sampling	Material	Soil Series.
1*	0 — ½	Augered at crest of hill.	Soil, A_3-horizon. Dark brown, leached, silty clay loam.	Marshall
2	½— 1	"	Soil, B-horizon. Medium brown, leached, silty clay loam.	
3	1 — 1½	"	"	
4	1½— 2	"	"	
5*	2 — 2½	"	"	
6	2½— 3	"	"	
7	3 — 3½	"	"	
8	3½— 4	"	Loess. Medum-textured, leached, light brown in color.	
9	4 — 4½	"	"	
10	4½— 5	"	"	
11*	5 — 5½	"	"	
12*	7 — 7½	Sampled down slope of road cut.	Loess. Medium-textured, calcareous, buff-colored. Some small lime concretions.	
13*	10 —10½	"	"	
14*	15 —15½	"	"	
15*	20 —20½	"	"	
----	23	No sample.	Loess. Medium-textured, leached, unoxidized, gray-colored.	
16*	25 —25½	Sampled down slope.	"	
17*	26 —26½	"	Loveland loess (?). Medium-textured, sandy, leached, medium brown in color.	
---	29	Reached with auger. No sample.	Glacial till.	

* In-place density tests made.

Redfield Section*.—West side of road cut 3 mi. west of Redfield, Dallas County, Iowa
NE corner, SW¼, Sec. 32, T. 79 N., R. 29 W.

Sample No.	Depth ft.	Method of Sampling	Material	Soil Series
1	0 — ½	Sampled down slope.	Soil, A-horizon (1 ft. thick). Dark brown, leached, silt loam.	Sharpsburg.
2	1½— 2	"	Soil, B_2-horizon. Medium brown, leached, silty clay loam. Blocky structure.	
3	2½— 3	"	Soil, B_3-horizon. Blocky structure fading out.	
4	5½— 6	"	Loess. Fine-textured, plastic, leached, medium-brown in color. Vertical jointing.	
5	8½— 9	"	"	
6	11 —11½	"	Loess. Plastic, leached, unoxidized, gray-colored. Grades down into 1 ft. of sandy material.	
7	12½—13	"	Mesotil. Heavy, brownish-black, blocky B-horizon developed on till.	

* Since sampling, this section has been considerably modified by a slump-block slide in the spring of 1953.

Red Oak Section.—South face of new gravel pit 4 mi. south of Red Oak, Montgomery County, Iowa.
SE¼, SW¼, Sec. 17, T. 71 N., R. 38 W.

Sample No.	Depth ft.	Method of Sampling	Material	Soil Series
1*	0 — ½	Sampled down slope of face in pit.	Soil, A_1-horizon. Dark brown, leached, silt loam.	Marshall.
2*	1 — 1½	"	Soil, A_3-horizon.	
3*	1½— 2		Soil, B_1-horizon. Medium brown.	
4*	2¼— 3¼	"	Soil, B_2-horizon.	
5*	3 — 3⅓	"	Soil, B_3-horizon.	
6*	3½— 4	"	Loess. Fine-textured, plastic, leached, buff in color	
7	6 — 6½	"	"	
8*	9 — 9½	"	"	
9*	12 —12½	"	"	
10*	15 —15½	"	"	
----	16½	No sample.	Loess. Fine-textured, plastic, leached, unoxidized. Gray-colored with red-brown and brown streaks.	
11*	17 —17½	Sampled down slope.	"	
12	18 —18½	"	"	
13*	18½—19	"	Glacial till	

* In-place density tests made.

Appendix B

Textural Composition of Depth Study Samples

Section	Sample No.	Depth, Ft.	Textural Composition Percent Sand		
			Sand	Silt	Clay
Crescent City	1	0 — ½	1.2	78.8	20.0
	2	2 — 2½	1.1	80.9	18.0
	3	5 — 5½	0.8	82.0	17.2
	4	10 — 10½	0.8	82.8	16.4
	5	15 — 15½	0.8	84.2	15.0
	6	20 — 20½	0.9	86.1	13.0
	7	25 — 25½	1.7	80.5	17.8
	8	30 — 30½	1.5	82.5	16.0
	9	35 — 35½	1.4	84.3	14.3
	10	40 — 40½	2.0	83.2	14.8
	11	45 — 45½	2.3	73.2	24.5
	12	50 — 50½	2.1	75.3	22.6
	13	60 — 60½	2.0	82.5	15.5
	14	65 — 65½	2.2	82.6	15.2
	15	70 — 70½	2.2	81.2	16.6
	16	75 — 75½	3.1	72.9	24.0
	17	80 — 80½	5.4	74.3	20.3
	18	85 — 85½	4.6	74.5	20.9
	19	90 — 90½	3.2	77.4	19.4
	20	95 — 95½	2.9	82.8	14.3
	21	100 —100½	4.7	81.2	14.1
	22	105 —105½	6.0	78.9	15.1
	23	110 —110½	3.6	83.1	13.3
	24	115 —115½	4.2	82.5	13.3
	25	120 —120½	2.2	83.8	14.0
	26	125 —125½	2.5	83.4	14.1
	27	135 —135½	5.2	81.8	13.0
	28	140 —140½	6.9	79.7	13.4
	29	145 —145½	9.9	76.1	14.0
	30	150 —150½	8.2	77.7	14.1
Turin	1	0 — ½	2.2	80.8	17.0
	2	2 — 2½	2.3	82.0	15.7
	3	10 — 10½	1.8	83.4	14.8
	4	20 — 20½	1.5	83.7	14.8
	4a	20 — 20½	2.9	83.2	13.9
	5	30 — 30½	2.7	83.9	13.4
	6	40 — 40½	1.9	81.1	17.0
	7	50 — 50½	2.1	84.3	13.6
	8	60 — 60½	1.8	84.1	14.1
	9	70 — 70½	1.1	83.5	15.4
	10	80 — 80½	1.8	78.2	20.0
	11	90 — 90½	0.2	85.4	14.4
	12	100 —100½	1.1	79.7	19.2
Pisgah	1	0 — ½	1.6	80.4	18.0
	2	2½— 3	2.4	85.2	12.4
	3	14½— 15	0.6	81.4	18.0
	4	21 — 22	0.6	80.5	18.9
	5	23½— 24	1.3	81.2	17.5
	6	25 — 25½	2.6	72.5	24.9
	7	28 — 28½	2.1	80.9	17.0

* Sand—Finer than 2mm. and coarser than 0.074 mm.
Silt—Finer than 0.074 mm. and coarser than 0.005 mm.
Clay—Finer than 0.005 mm.

Section	Sample No.	Depth, Ft.	Textural Composition*, Percent		
			Sand	Silt	Clay
Soldier	1	0 — 1	0.8	72.7	26.5
	2	1 — 2	1.5	73.7	24.8
	3	3 — 3½	1.1	74.6	24.3
	4	10 — 10½	0.7	77.2	22.1
	5	20 — 20½	0.8	77.2	22.0
	6	30 — 30½	0.6	79.6	19.8
	7	40 — 40½	0.3	77.7	22.0
	8	50 — 50½	1.0	76.2	22.8
	9	58 — 58½	0.5	75.2	24.3
	10	58½— 59	1.1	68.4	30.5
Harlan	1	0 — ½	1.3	60.6	38.1
	2	½— 1	0.6	59.7	39.7
	3	1 — 1½	0.8	61.7	37.5
	4	1½— 2	1.1	64.0	34.9
	5	2 — 2½	0.7	66.0	33.3
	6	2½— 3	0.5	66.8	32.7
	7	3 — 3½	0.8	66.4	32.8
	8	3½— 4	0.5	69.0	30.5
	9	4 — 4½	0.3	69.9	29.8
	10	4½— 5	0.5	68.5	31.0
	11	5 — 5½	0.6	70.0	29.4
	12	7 — 7½	0.6	70.1	29.3
	13	10 — 10½	0.9	73.8	25.3
	14	15 — 15½	0.5	74.7	24.8
	15	20 — 20½	0.7	76.3	23.0
	16	25 — 25½	0.6	69.4	30.0
	17	26 — 26½	8.6	63.2	28.2
Red Oak	1	0 — ½	0.9	66.6	32.5
	2	1 — 1½	0.4	59.1	40.5
	3	1½— 2	0.4	58.6	41.0
	4	2½— 2¾	0.4	56.6	43.0
	5	3 — 3⅜	0.3	57.5	42.2
	6	3½— 4	0.5	59.7	39.8
	7	6 — 6½	0.4	63.9	35.7
	8	9 — 9½	0.3	68.8	30.9
	9	12 — 12½	0.4	70.3	29.3
	10	15 — 15½	0.9	76.3	22.8
	11	17 — 17½	0.6	72.6	26.8
	12	18 — 18½	2.7	68.3	29.0
	13	18½— 19	12.5	60.3	27.2
Redfield	1	0 — ½	8.0	65.0	27.0
	2	1½— 2	1.1	54.9	44.0
	3	2½— 3	1.0	54.0	45.0
	4	5½— 6	0.9	64.5	34.6
	5	8½— 9	0.7	71.3	28.0
	6	11 — 11½	0.5	71.7	27.8
	7	12½— 13	33.0	19.2	47.8

* Sand—Finer than 2mm. and coarser than 0.074 mm.
Silt—Finer than 0.074 mm. and coarser than 0.005 mm.
Clay—Finer than 0.005 mm.

PROPERTY VARIATIONS IN THE WISCONSIN LOESS OF EAST-CENTRAL IOWA

by

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(Iowa Academy of Science Proceedings 61:291-312. 1954.)

The east-central Iowa area has Wisconsin-age loess as its most abundant surficial material. The area studied is bounded on the west by the Cary drift border, and on the north by the Iowan and Tazewell drift borders (figure 1).

Initial samples were taken from twenty-three loess sections exposed in road cuts or quarries (figure 2). Samples were taken to show the maximum soil profile development in each section, and to show any vertical variations in the loess. Sampling was done at hilltop positions, since the loess there is quite often thicker and less disturbed. A practical reason for sampling at hilltops is related to the present-day need for level roads, which requires that hills be cut down, and the material used to fill in the valleys. Hilltop materials are therefore of importance for road construction.

In addition to the twenty-three sections studied in detail, single samples

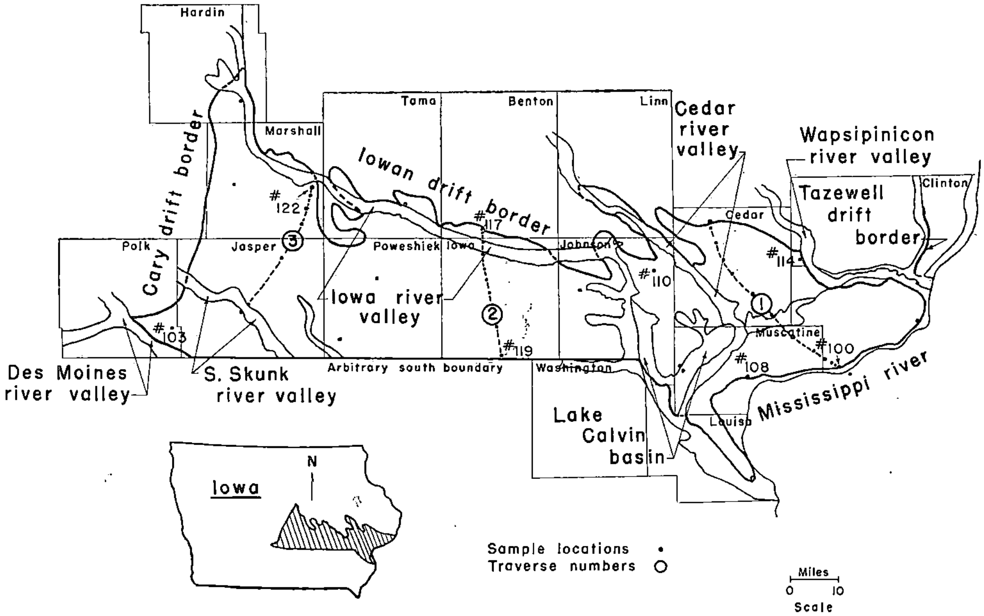

Fig. 1. Locations of samples and traverses in the east-central Iowa loess area. .

were taken from the C-horizon at a constant depth of about 7½ feet along three traverses (figure 1). The traverse samples were taken to show more precisely the areal variations in the loess. Since the data previously obtained from the twenty-three sections showed a more rapid change in properties near the Iowa drift border and near the Mississippi River, traverse samples were spaced more closely at these locations.

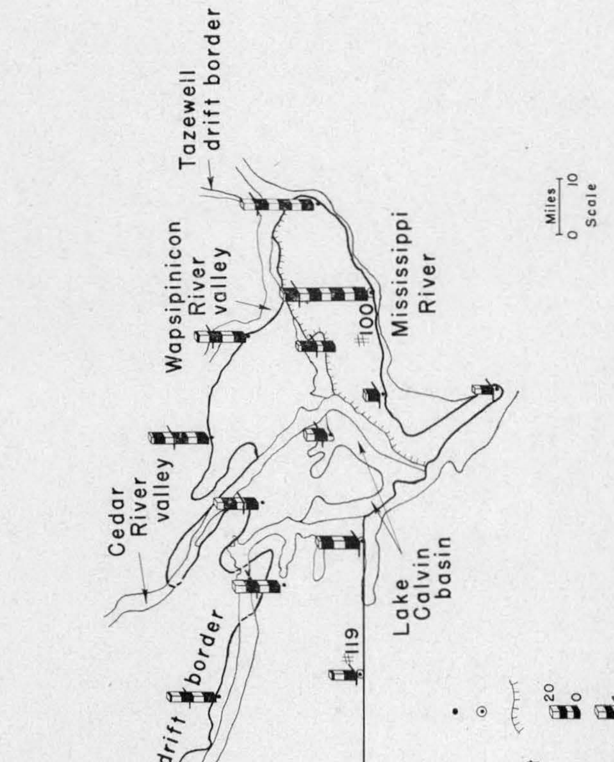

Fig. 2. Depth of Wisconsin loess at sampling locations in east-central Iowa.

OCCURRENCE AND THICKNESS

In east-central Iowa, the loess is a rather uniform mantle over erosional hills of older deposits (figure 3). Most commonly it overlies Kansan till upon

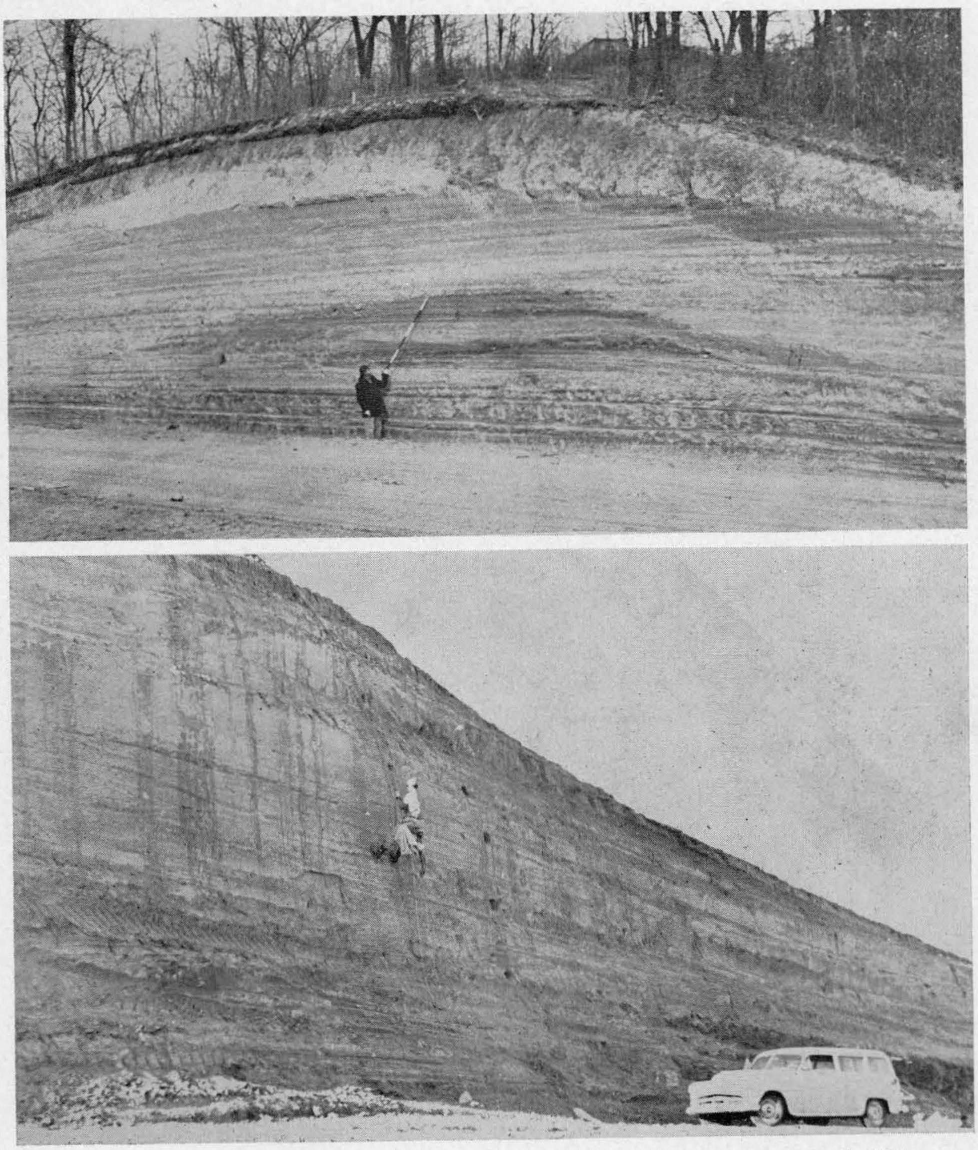

Fig. 3. Above. Wisconsin loess capping a hill in the dissected Illinoian drift plain adjacent to the Mississippi River. The location is at LeClaire, Iowa.
Below. Sampling section 100 in a quarry near Buffalo, Iowa. Studies indicate that adjacent to the Mississippi River floodplain the deep, friable loess is dolomitic and is not extensive in Iowa.

which a soil profile has developed (i.e., gumbotil and ferreto). In the eastern part of the area, the loess is over Illinoian till and gumbotil (figure 2). In some areas, the loess overlies alluvial or outwash deposits.

The loess is thickest along the Iowan drift border and along some of the major streams (figure 2). Along the Mississippi River north of Muscatine, the Wisconsin loess in the two sections measured averages about 35 feet thick. Near the Iowan drift border, a maximum thickness of about 50 feet was measured north of Le Grand (Section 122). Other thicknesses measured near the Iowan drift border average about 25 feet. Along the arbitrary south boundary of the area, the thickness measurements average about 15 feet, and a section adjacent to the Skunk River measured 23 feet. South of Muscatine, depth measurements indicate no increase in loess thickness adjacent to the Mississippi River floodplain, but show only a continuation of the trend of southeasterly thinning away from the Iowan drift border.

It is interesting to speculate upon this absence of thick loess where it should be thickest, adjacent to a floodplain source, especially since here the floodplain is wider and was presumably a better source area. An explanation may be that the Mississippi flows west above Muscatine, and here the deep loess is present north of the river in Iowa. A prevailing northwest wind might occasionally blow up-river from the west and deposit material on the north side of the river. South of Muscatine, the river valley runs south, so a major change in wind direction would be necessary for material to be carried to the west into Iowa. The loess is thick on the Illinois side of the river[12].

Studies were made of a section in the area of glacial Lake Calvin (figure 2). The section from which soil samples were taken is located west of Nichols on the intermediate terrace[10]. Since Lake Calvin is believed to have been drained prior to Wisconsin time, some Wisconsin loess would be expected on the lake plain. The section sampled was about 17 feet of loess-like silt grading downward into fine sand. A brownish loess-like material averages about 4 feet thick in the Lake Calvin area exclusive of the present floodplains[10]. However, Lake Calvin materials constitute a separate engineering problem because of a high water table. The high ground water level and poor drainage also have affected soil profile development.

FIELD DESCRIPTION

Loess in east-central Iowa displays typical massive structure, and commonly shows secondary lime concretions and iron concentrations, root tubules, etc. The more friable loess will stand in vertical cuts (figure 3).

A faint pseudo-stratification sometimes may be observed in weathered cuts in the loess (figure 4). The stratification is not continuous and frequently is not horizontal, and pieces of the loess do not break along planes as do many alluvial silts. Such stratification is probably due to modification

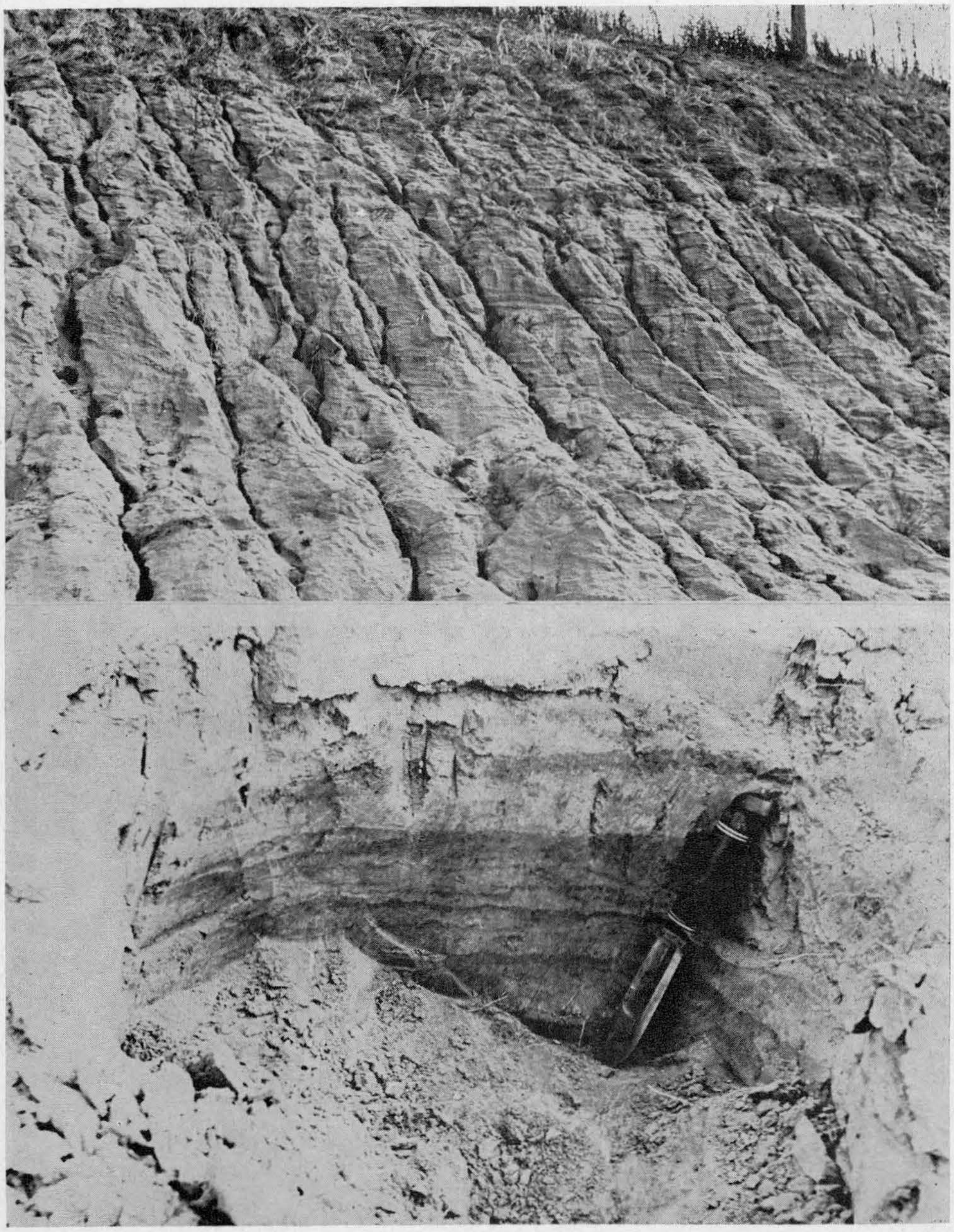

Fig. 4. Above. Pseudo-stratification in the loess at a sample location near the Wapsipinicon River. Such stratification is not common in the Wisconsin loess of east-central Iowa. Where present it is most noticeable on weathered cuts such as the one pictured.
Below. Clay-rich bands in the lower B horizon. The location is the same as above. Fayette soil series.

of the loess by rain, puddling, and sheet water during the time of deposition[2].

Layers and inter-fingerings of sand in the lower half of the loess were noted at a number of sampling locations. A gray, gritty material under the loess often appears to be part of the buried soil profile on the Kansan till.

In the section shown in figure 4 and in some other sections examined, banding was noticed in the transition from the B to the C horizon. The bands are brownish in color, usually ½ to 2 inches in thickness, and are better cemented than the adjacent lighter-colored material. Differential thermal analyses indicate the bands to be primarily the result of clay concentrations.

Along the Iowa River and near the Iowan drift border, the depth of leaching varies from 4½ to 10 feet; the lower values were observed in the northwestern part of the area (figure 2). To the east, the deep loess adjacent to the Mississippi River floodplain is leached 7 or 8 feet. In the southeast part of the area, where the loess near the Mississippi is thin, the entire section is leached. In the remainder of the east-central Iowa area, leaching tends to be greater, and along the south border of the area, the sections are completely leached. A few of the calcareous loess sections contained basal leached zones, possibly equivalent to the Farmdale loess in Illinois. Loess of Loveland age was not recognized in any of the sections.

Most of the loess-derived soils in the area studied are of the Tama, Muscatine, and Fayette soil series[11]. Profile development commonly extends to depths of 3 to 5 feet. The B horizon is in general 2 to 3 feet thick and shows a well-developed blocky structure. The transition into the C-horizon is gradual, particularly in the more plastic loess, where the B-horizon blocks increase in size and merges into the C-horizon. In the shallower loess, the soil profile constitutes from one-third to one-half of the section.

The color of the loess is mainly an evidence of the oxidation condition. The loess is well oxidized and yellowish-brown or light yellowish-brown in color except where oxidation has been restricted by ground water conditions. Ground water is usually above where the loess is in contact with underlying less permeable materials.

In the flat upland areas of undissected Kansan and Illinoian till plains, much of the loess is below the water table, and the loess below the water table is usually gray or brownish gray in color. Frequently there is an intermediate zone of mottling above the gray loess, probably due to seasonal fluctuations in the height of the water table. Occasionally, the basal loess below the water table is bluish in color and has a swampy odor. In Nebraska, the bluish color has been related to stagnate ground water conditions[2].

Secondary deposits of calcium carbonate and iron and manganese compounds are common in the loess. Carbonate concretions up to one-half inch in diameter are commonly found in calcareous loess above an impermeable layer, and small spots of lime may be found higher in the section but below the leached zone. The iron and manganese compounds occur as small black, yellow-brown, or red-brown spots, stains, and concretions throughout the loess. Iron cemented concretions, which may be either hard or soft, occasionally grow to several inches in diameter, and because of the color difference they are most noticeable in the gray basal portion of the loess.

PARTICLE SIZE

Mechanical analyses showed textural variations with depth in the twenty-three sections (figure 2)[3]. In the particle-size variations in three loess sections (figure 5) the Quarry section (No. 122) is typical of deep loess near the Iowa River, the Buffalo section (No. 100) is typical of the rather limited deep loess on the Iowa side of the Mississippi River, and the North English section (No. 119) is typical of the shallow, plastic loess along the south boundary of the area.

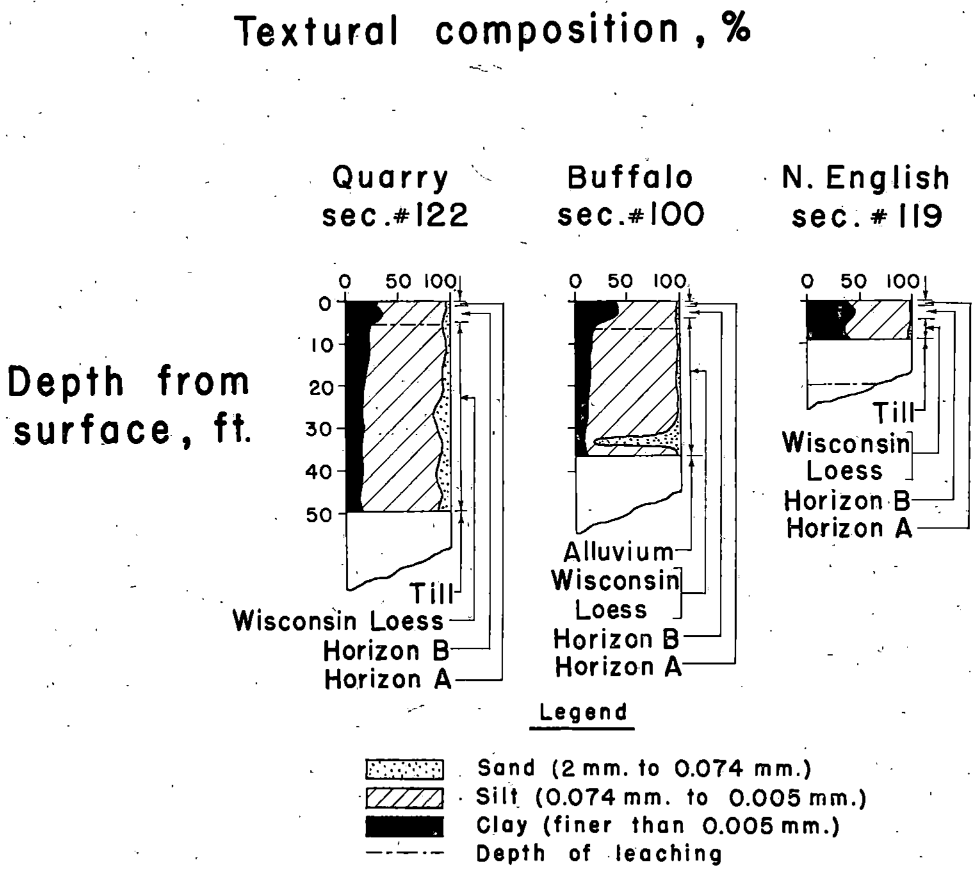

Fig. 5. Variation of textural composition with depth in three selected sections of Wisconsin loess.

Fine sand is common in the east-central Iowa loess, particularly in the deeper loess near the Iowan drift border and some major river valleys. The sand is in layers and thin lenses, and more is usually in the lower parts of the sections. Very little sand is in the shallow, plastic loess in the south-central part of the area. Most of the sections show rather uniform clay contents below the influence of the B horizon, with slight increases in clay at the base of the loess (figure 5).

Mechanical analyses of samples along the traverses (figure 1) illustrate the textural variations in the area. These data (figure 6) represent C-horizon samples taken usually at a depth of 7½ to 8 feet below the surface of the ground. The percentages of sand in the loess show marked increases

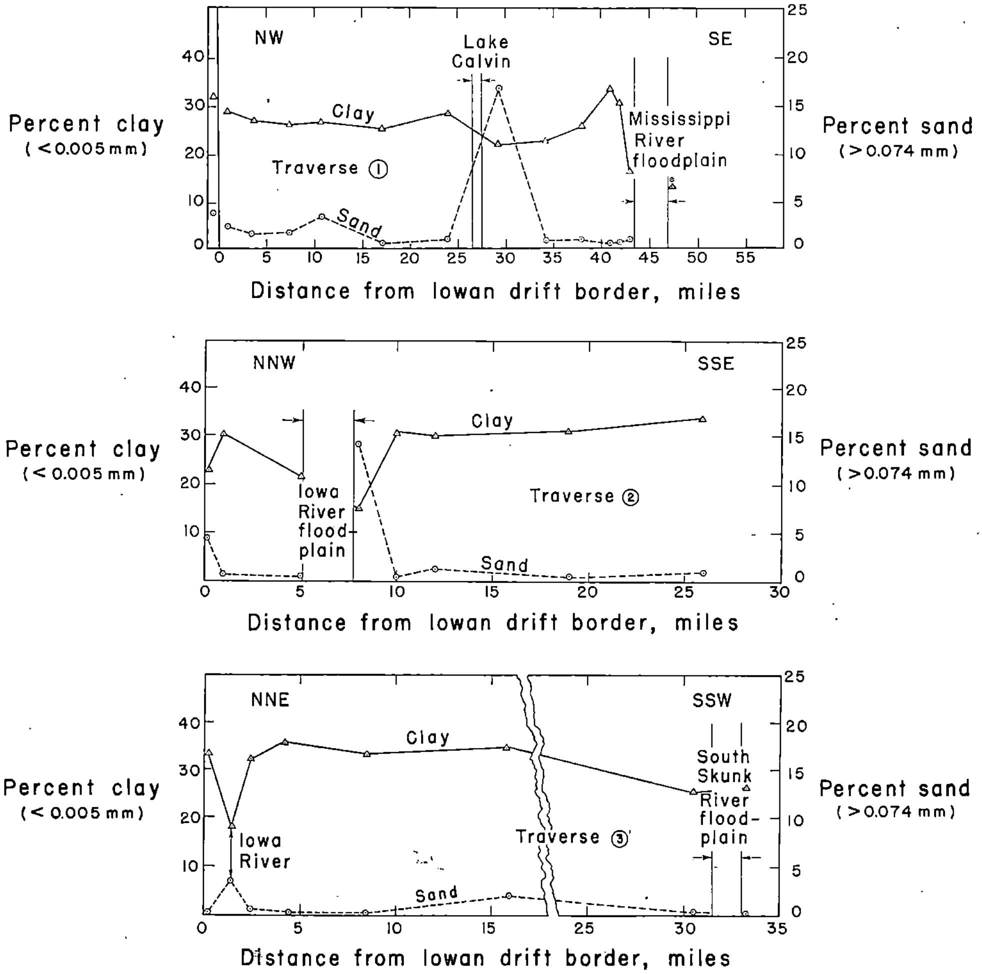

Fig. 6. Variation in clay and sand contents with distance from the Iowan drift border along traverses 1, 2, and 3.

south of the Iowa River floodplain and southeast of the northeast arm of Lake Calvin. Along traverse 2, the loess is sandy near the Iowan drift border. Traverse 1 includes a sample from thin loess on the Iowan drift; the sample was necessarily taken at a shallower depth, and may be influenced by soil profile development.

Clay percentages in the loess show sharp decreases near the Iowa River floodplain: the decrease is greater here than near the Iowan drift border. Traverse 2 shows these two separate influences. Along traverse 3 the clay decreases in loess south of the Iowa River and near the South Skunk River floodplain. Small differences in clay contents in the traverse samples probably are not significant because of depth variations in the sections.

Along traverse 1, the Lake Calvin influence appears to extend about fifteen miles to the southeast, or almost to the Mississippi River floodplain. The peak clay content between Lake Calvin and the Mississippi River floodplain appears to be a continuation of the gradual rise in clay content away from the Iowan drift border. This peak content is found within 2 to 3 miles of the Mississippi River floodplain. Closer to the floodplain, the clay content drops abruptly.

These data would indicate that the Iowa River floodplain was an important source area for the loess. However, this influence does not extend over five or ten miles away from the river, indicating that a more distant source area, such as the Iowan drift plain or outwash from the receding Iowan, may have contributed most of the loess. The direct influence of the border of the Iowan drift appears to be slight, and relationships previously ascribed to the drift border[8] are probably mainly due to the Iowa River source area. This is further illustrated by traverse 1, where the Iowan drift border is not paralleled by the Iowa River, and no significant decrease in clay was found.

The decrease in clay contents near the northeast arm of Lake Calvin would indicate that this was a source area. While there is no major stream in this area now, the evidence suggests that it was a route for glacial outwash, possibly either Iowan or Tazewell or both.

The clay content data show the areal variations in clay content in C-horizon Wisconsin loess (figure 7). The map drawn from data from the sample traverses and sections, is subject to revision. Present data are most limited in the Cedar and Wapsipinicon river areas.

ENGINEERING PROPERTIES

Data in table I are for three samples typical of the C-horizon loess in the three sections (figure 5). The plasticity index, which is the difference between the liquid limit and the plastic limit, is higher with higher clay contents; the shrinkage limit is lower with higher clay contents. The Bureau of Public Roads engineering classification of soils is made with plasticity index, liquid limit, and particle-size data. Group A-4 includes friable, silty

TABLE I. ENGINEERING PROPERTIES OF THREE SELECTED C-HORIZON LOESS SAMPLES

Engineering Properties		Sample No. 100-8*	122-6†	119-5‡	Test Method
Liquid Limit, %		27.1	26.8	38.4	AASHO Method T89-49
Plastic Limit, %		19.8	17.6	17.2	AASHO Method T90-49
Plasticity Index		7.3	9.2	21.2	AASHO Method T91-49
Shrinkage Limit, %		20.6	18.9	17.4	AASHO Method T92-42
B.P.R. Engineering Classification		A-4 (8)	A-4 (8)	A-6 (13)	AASHO Method M145-49
Specific Gravity, 25°C		2.72	2.71	2.70	AASHO Method T100-38
Capillary Rise, In.		76	50	36	Essentially the same as The "Suggested Method of Test for Capillary Rise of Soil"[11]
Standard Proctor Density Test	Max. Dry Density lb./cu. ft.	110.6	113.2	110.3	AASHO Method T99-49
	Optimum Moisture Content, %	15.8	15.1	16.6	
California Bearing Ratio of Soil at Standard Proctor Density, %	At Optimum Moisture	18.4	27.6	13.1	Essentially the same as the "Suggested Method of Test For California Bearing Ratio of Soils"[11], except that specimens prepared are at maximum moisture content determined by standard Proctor density tests.
	After 4-Day Soaking	15.0	22.2	4.8	

* Representing friable loess adjacent to the Mississippi R. floodplain.

† Representing friable loess near the Iowa River.

‡ Representing medium-textured loess in the south part of the E.-Central Iowa area.

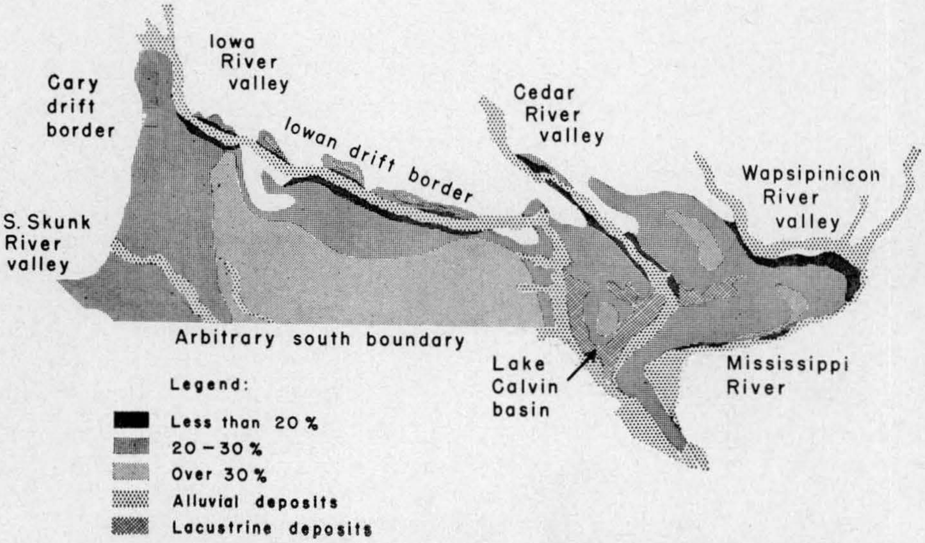

Fig. 7. Approximate areal variation in the clay content (<0.005 mm) of the C-horizon Wisconsin loess in east central Iowa.

soils, and Group A-6 includes moderately plastic, clayey soils. The group index, indicated by a number in parenthesis, permits further evaluation within a group.

The capillary rise test is essentially a measurement of the maximum head of water a column of initially loose, wet soil will support before air breaks through. The data show trends similar to those found for southwestern Iowa loess[7]. In the Proctor density test, Sample 122-6 compacts to a higher density, probably because of the higher sand content and resulting less uniform gradation. This is also reflected in the higher bearing capacity of this soil, as measured by the California Bearing Ratio. The drop in bearing capacity after soaking is greatest for clayey sample 119-5.

Table II presents data which show some property variations through the soil and weathering profiles in a few of the loess sections sampled. The data show the pronounced effect of soil profile development on engineering properties. The plasticity index increases with increasing clay content, regardless of soil horizon (figure 9). Not only is this important from the standpoint of soil stabilization, but it suggests either a uniformity in clay mineral composition or perhaps a uniform clay mineral variation depending on clay content. In southwestern Iowa, the ratio of montmorillonite to illite increases with increasing clay content in the C-horizon loess[6]. All of the A-4 samples are from the C-horizon of sections near the floodplains of the Iowa, Wapsipinicon, or Mississippi rivers.

In-place densities and field moisture contents were measured at various depths in the three detailed study sections (figures 2, 10). The effect of soil profile development on in-place density and field moisture content is

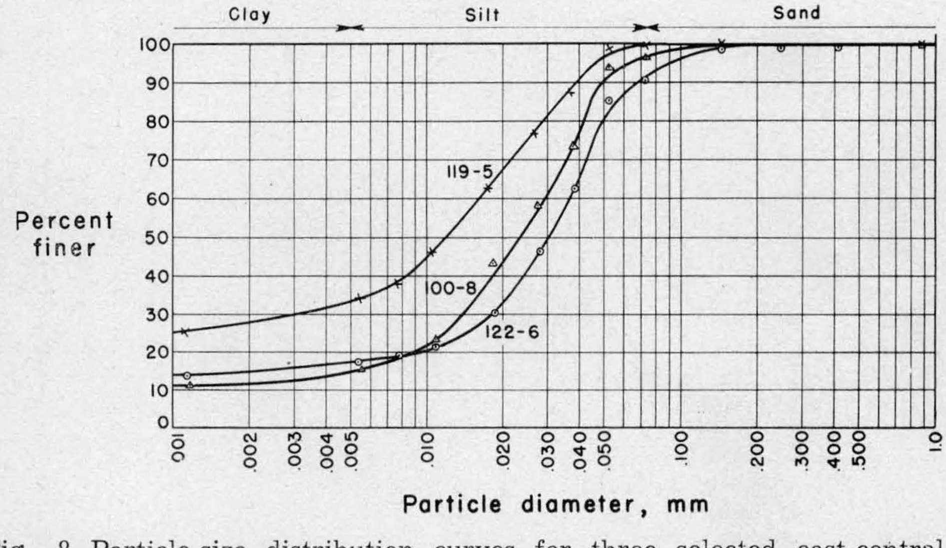

Fig. 8. Particle-size distribution curves for three selected east-central Iowa loess samples.

TABLE II. PROPERTY VARIATIONS THROUGH THE SOIL AND WEATHERING PROFILES OF SOME WISCONSIN LOESS SECTIONS.

Sample No.	Section location	Soil series	Horizon	Depth of sampling, ft.	Plastic limit, %	Liquid limit, %	Plasticity index %	B.P.R. classification Engineering	B.P.R. classification Textural
100-1	Scott County	Muscatine	A	¼-¾	18.7	41.5	22.8	A-7-6(14)	Silty clay
	Buffalo Township								
100-2	(T-77N, R-2E)		B	2-2½	17.4	50.4	33.0	A-7-6(18)	Silty clay
	N½SW¼ Sec. 13								
100-4	(Along Mississippi River)		C†	5½-6	21.2	30.9	9.7	A-4(8)	Silty loam
100-8			C*	25-25½	19.8	27.1	7.3	A-4(8)	Silty loam
103-1	Polk County	Tama	A	0-¾	23.3	43.7	20.4	A-7-6(13)	Silty clay
	Beaver Township								
103-2	(T-79N, R-22W)		B	2½-3	18.9	52.9	34.0	A-7-6(19)	Silty clay
	SE¼SE¼ Sec. 35								
103-5	(At SW corner of area)		C†	8-8½	19.7	34.6	14.9	A-6(10)	Silty clay
108-1	Muscatine County	Fayette	A	0-½	21.6	32.1	10.5	A-6(8)	Silty clay loam
108-2	Bloomington Township		B	2½-3	19.8	52.2	32.4	A-7-6(18)	Silty clay
108-4	(T-77N, R-2W)		C†	6-6½	18.2	35.6	17.4	A-6(11)	Silty clay loam
	NE¼SE¼ Sec. 33								
	(Along Mississippi River)								
110-1	Johnson County	Fayette	A	0-½	25.1	37.6	12.5	A-6(9)	Silty clay loam
	Graham Township								
110-2	(T-80N, R-5W)		B	3-3½	17.1	49.9	32.8	A-7-6(14)	Silty clay
	SE¼SW¼ Sec. 9								
110-4	(In E. central part of area)		C†	7½-8	18.0	37.9	19.9	A-6(12)	Silty clay loam
110-6			C*	15½-16	19.5	30.8	11.3	A-6(8)	Silty clay loam

* C-horizon, oxidized.
† C-horizon, oxidized and leached.
Unmarked: C-horizon, unoxidized and unleached.

TABLE II (CONTINUED)

Sample No.	Section location	Soil series	Horizon	Depth of sampling, ft.	Plastic limit, %	Liquid limit, %	Plasticity index %	B.P.R. classification Engineering	B.P.R. classification Textural
114-1	Clinton County Spring Rock Township	Fayette	A	0-½	21.2	33.1	11.9	A-6(8)	Silty clay loam
114-2	(T-81N, R-1E) SW¼SW¼ Sec. 22		B	2-2½	18.8	49.3	30.5	A-7-6(18)	Silty clay
114-5	(Along Wapsipinicon River)		C†	7-7½	19.2	29.1	9.9	A-4(8)	Silty loam
114-7			C*	15-15½	19.2	26.6	7.4	A-4(8)	Silty loam
117-1	Benton County Leroy Township	Fayette?	A	0-½	23.2	34.1	10.9	A-6(8)	Silty clay loam
117-2	(T-82N, R-11W) NW¼SW¼ Sec. 34		B	2-2½	17.9	47.7	29.8	A-7-6(17)	Silty clay
117-5	(Along Iowan drift border)		C†	7-7½	19.1	38.1	19.0	A-6(12)	Silty clay
117-7			C	15-15½	20.3	33.6	13.3	A-6(9)	Silty clay loam
119-1	Iowa County Fillmore Township	Fayette	A	0-½	24.1	38.5	14.4	A-6(10)	Silty clay
119-2	(T-78N, R-10W) NE¼NW¼ Sec. 31		B	1 5/6-2⅓	19.4	52.9	33.5	A-7-6(19)	Silty clay
119-5	(Along S. edge of area)		C†	6-6½	17.2	38.4	21.2	A-6(13)	Silty clay
122-1	Marshall County LeGrand Township	Tama	A	0-½	25.9	43.9	18.0	A-7-6(12)	Silty clay loam
122-2	(T-83N, R-17W) NE¼SE¼ Sec. 3		B	1 5/6-2⅓	17.1	44.0	26.9	A-7-6(16)	Silty clay
122-4	(Along Iowa River)		C*	6-6½	21.0	31.4	10.4	A-4(8)	Silty loam
122-6			C*	14-14½	17.6	26.8	9.2	A-4(8)	Silty loam
122-8			C*	24-24½	17.9	24.7	6.8	A-4(8)	Silty loam
122-10			C*	34-34½	19.5	26.4	6.9	A-4(8)	Silty loam

* C-horizon, oxidized.
† C-horizon, oxidized and leached.
Unmarked: C-horizon, unoxidized and unleached.

marked, and in general, both properties show increases in the B-horizon. Below the influence of soil profile development in the C-horizon, the in-place density increases slightly with depth, from 80 or 85 lb. per cu. ft. to about 90 lb. per cu. ft. In Section 100, density increases greatly near the base of the loess section, suggesting a puddling influence from the water table. The clay content in the lower few feet of this section, as in most of the other loess sections, gradually increases towards the basal contact of the Wisconsin loess with underlying material. In many of the sections, immediately above the zone of clay increase, there is a zone low in clay, suggesting possible movement downward caused by a fluctuating water table.

PETROGRAPHY

Methods

Detailed petrographic studies were made on three C-horizon samples from the detailed study sections. Sample 100-8 represents the deep, friable, calcareous loess adjacent to the Mississippi River floodplain; 122-7 represents deep, friable calcareous loess near the Iowa River, and 119-5 represents shallow, moderately plastic, leached loess in the south-central part of the

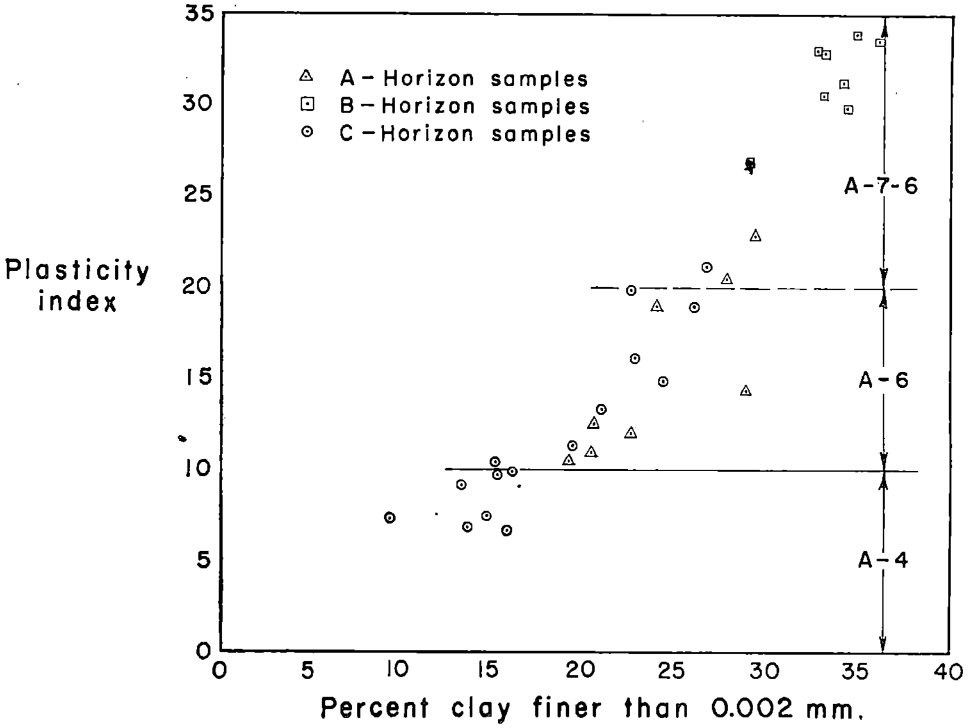

Fig. 9. Relationship between plasticity index and clay content. The B.P.R. classification for engineering use is shown to the right. Note that B-horizonsamples are grouped high in the A-7-6.

area. The samples were dispersed as for a mechanical analysis, and separated into size fractions by elutriation[7]. Each size fraction down to 0.005 mm. was then separated into heavy and light mineral fractions and analyzed under a petrographic microscope. Clay minerals in the three loess samples have so far been studied by clay-mineral staining[9] and by differential thermal analysis of the whole loess. In addition, chemical properties of these and other loess samples were determined with chemical tests and differential thermal analysis.

Microscopic Studies

Results of microscopic studies of the sand and silt fractions are presented in table III. The dominant minerals in all samples are quartz and feldspar. Heavy mineral percentages exclusive of dolomite are about 4 to 5 percent. Carbonate percentages vary from a trace in the leached sample (119-5) to over 20 percent in the Mississippi River sample (100-8). The latter includes at least 5.3 percent dolomite determined on the basis of specific gravity. The proportion of dolomite in the carbonates is probably even higher than indicated, since the calcite-dolomite separation at specific gravity 2.89 favors calcite.

In the three samples, quartz increases and feldspar tends to decrease with

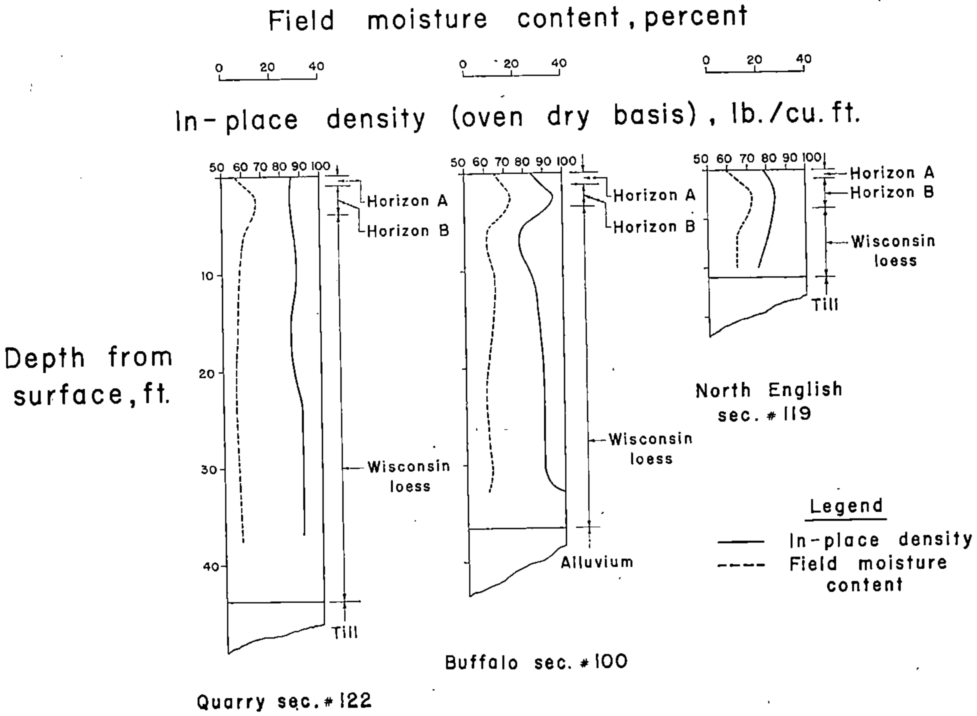

Fig. 10. Variation of in-place density and of field moisture content with depth in three selected sections of Wisconsin loess.

increasing clay content. Similar trends in the Wisconsin loess of southwestern Iowa are believed due to greater weathering in the high clay content loess[6].

Shapes of individual mineral grains may be expressed as sphericity, a perfect sphere having a sphericity of 1.0. The average sphericity of grains in each of the three samples is 0.76. The same value for sphericity was measured in the loess of southwestern Iowa[7]. The sharpness of the grain corners, which is measured independent of sphericity, averages between angular to subangular.

Clay coatings and iron-oxide stains are common on the loess grains. Frosting and pitting of grain surfaces were also noted.

Clay Minerals

In the clay-mineral studies of the east-central Iowa loess, staining tests of minus 0.005 mm. clay indicated montmorillonite in the three samples. Differential thermal curves for the three whole loess samples (figure 11) show that the clay-mineral reactions are very similar to those found in southwestern Iowa loess, where the minerals are identified as montmorillonite and illite[6].

TABLE III. MINERALOGICAL COMPOSITION OF THREE LOESS SAMPLES
(All Percentages are by Volume of the Solids in the Whole Sample)

Mineral Composition	100-8	122-6	119-5
Whole Loess, Totals			
Quartz	45.2	49.4	50.3
Feldspar	16.6	17.1	12.0
Carbonate	20.3	12.8	0.3
Heavy Minerals*	4.6	4.4	5.1
Others	1.3	0.5	0.3
Clay†, <0.005 mm.	12.0	15.8	32.0
Light Fraction			
Undifferentiated quartz	41.3	46.0	46.2
Iron-oxide coated quartz	1.7	1.6	1.5
Clay-coated quartz	2.2	1.8	2.6
Undifferentiated feldspar	14.7	13.9	10.5
Plagioclase	0.1	Tr.	-----
Microcline	0.1	-----	-----
Altered feldspar	1.7	3.2	1.5
Calcite	15.0	11.7	0.3
Muscovite	0.4	-----	0.4
Clay aggregates and rock fragments	0.4	0.3	Tr.
Glauconite	0.2	0.2	Tr.
Heavy Fraction			
Dolomite	5.3	1.1	-----
Amphibole	0.7	1.1	1.0
Pyroxene	0.2	0.3	0.2
Iron-oxides	2.1	2.2	3.0
Biotite and muscovite	0.3	0.2	0.5
Topaz	0.4	0.2	0.2
Tourmaline	0.2	0.2	Tr.
Epidote	0.4	0.2	Tr.
Epidote	0.4	0.2	Tr.
Others	0.3	Tr.	Tr.

* Dolomite is included in the carbonate percentage.
† This material not analyzed microscopically.

Chemical Tests

The sampling depths and locations of the loess sections have been given (table III). The three samples analyzed petrographically were studied somewhat more in detail chemically (table IV). No soluble chlorides and sulfates were found in these three samples. The cation exchange capacity increases with increasing clay content; the pH is lowered by leaching.

Chemical tests through the soil profile indicate that for soil stabilization purposes, organic matter is very high in the A-horizon and significant in the B-horizon. From 2 to 4 percent is usually present in the A-horizon, and in some over 0.5 percent was found in the B-horizon. In the C-horizon, the organic matter content is low and rather uniform. The effect of organic matter in stabilization depends also on its reactivity, so the values may not truly indicate engineering behavior.

Calcium and magnesium ion contents were determined by leaching the samples 1.5 N.HC1 and titrating with versenate (table IV). The values for A and B horizon samples and leached C-horizon samples are probably due to Ca and Mg cations from the exchange sites of the organic matter and clay minerals. High Ca-Mg contents in the unleached C-horizon samples are mainly due to the carbonates (table IV). The carbonate contents correlate closely with those from microscopic examination. The highest carbonate contents were measured in C-horizon samples near the Iowa, Wapsipinicon, or Mississippi rivers.

Carbonates are indicated more specifically on differential thermal curves, and dolomite may be differentiated from calcite. The top curve in figure 11 is for sample 100-8 without pretreatment. The large peak at about 850°C. indicates the final decomposition of calcium carbonate; the smaller

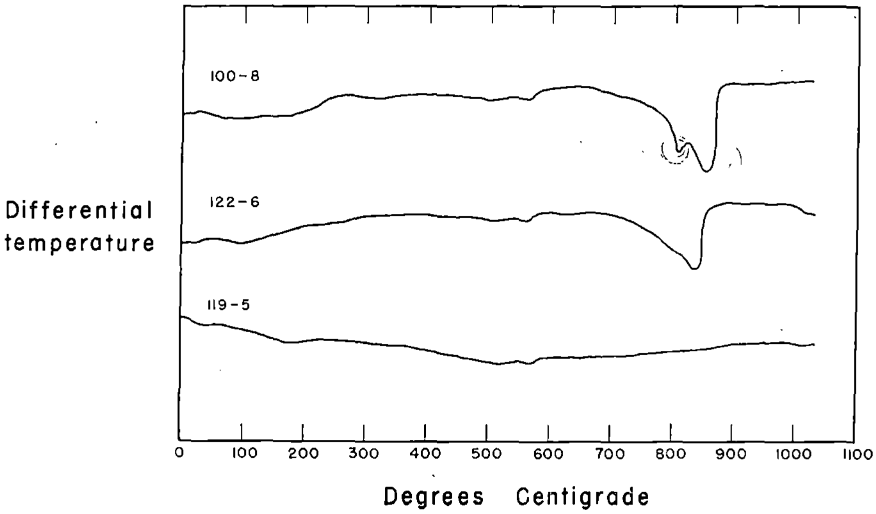

Fig. 11. Thermal curves of three selected whole loess samples.

peak at about 800°C. indicates the breakdown of magnesium carbonate. Since the mineral dolomite is $CaMg(CO_3)_2$, part of the large reaction at 850°C. is due to the calcium carbonate in this mineral. Microscopic analysis of the sample also revealed at least 5 percent dolomite. Since north of sample location 100, the Mississippi cuts through large amounts of dolomitic rocks, this is confirming evidence that the river and its floodplain were probably the source for the small area of deep-friable loess on the Iowa side of the river (figure 12). Dolomite has been reported in the loess of Illinois[13], and during a recent southern trip, samples of Wisconsin loess were collected at thirteen locations down the Mississippi River valley from Illinois to south of Natchez, Mississippi. Other sampling locations are east of the lower Mississippi River floodplain. Thermal curves representing samples from locations in figure 12 indicate the presence of dolomite in the loess as far south as Mozier, Illinois (figure 13). Dolomite was also indicated in Wisconsin loess samples from the following locations: south of East St. Louis near Dupo, Illinois; in northwest Tennessee near Tiptonville; in northwest

TABLE IV. CHEMICAL DATA ON SAMPLES FROM SELECTED LOESS SECTIONS

Sample No.	Soil Horizon	Organic Matter, %*	Total Ca^{++} & Mg^{++} Det. by leaching†	Ca^{++} & Mg^{++} Expressed as % $CaCO_3$*	PH	Free Iron, %*	Cat. Exch. Cap.†
100-1	A	1.2	28	----	----	----	----
-2	B	0.3	23	----	----	----	----
-4	C‡	0.1	24	----	----	----	----
-8	C	0.2	200	20.0	7.9	0.5	3.79
103-1	A	3.2	22	----	----	----	----
-2	B	0.4	27	----	----	----	----
-5	C	0.2	79	7.9	----	----	----
108-1	A	2.1	23	----	----	----	----
-2	B	0.4	23	----	----	----	----
-4	C‡	0.2	16	----	----	----	----
110-1	A	2.9	17	----	----	----	----
-2	B	0.3	25	----	----	----	----
-4	C‡	0.1	24	----	----	----	----
-6	C	0.2	103	10.3	----	----	----
114-1	A	2.1	17	----	----	----	----
-2	B	0.5	23	----	----	----	----
-5	C‡	0.1	20	----	----	----	----
-7	C	0.1	143	14.3	----	----	----
117-1	A	2.4	14	----	----	----	----
-2	B	0.4	30	----	----	----	----
-5	C‡	0.2	24	----	----	----	----
-7	C	0.2	99	9.9	----	----	----
119-1	A	4.6	17	----	----	----	----
-2	B	0.7	24	----	----	----	----
-5	C‡	0.3	18	----	5.7	1.1	15.28
122-1	A	4.6	24	----	----	----	----
-2	B	0.4	30	----	----	----	----
-4	C	0.1	150	15.0	----	----	----
-6	C	0.1	131	13.1	8.0	0.4	4.28
-8	C	0.1	77	7.7	----	----	----
-10	C	0.1	68	6.8	----	----	----

* Percent at oven-dry weight of whole soil sample.
† Expressed as m.e. per 100 gm. of oven-dry soil.
‡ C.Horizon, leached.

Mississippi near Eudora; east of Greenwood, Mississippi; and south of Vicksburg, Mississippi, near the Big Black River. The dolomite thermal reactions in these samples are about the same as in the sample from Mozier, Illinois (figure 13). Exceptions are the Eudora and Big Black River samples, which gave very strong dolomite reactions. Samples from three locations in the vicinity of Natchez, Mississippi, show only traces of dolomite. These and other reactions shown by the thermal curves of the thirteen samples indicate a similarity in composition and therefore a possible similarity in stabilization behavior.

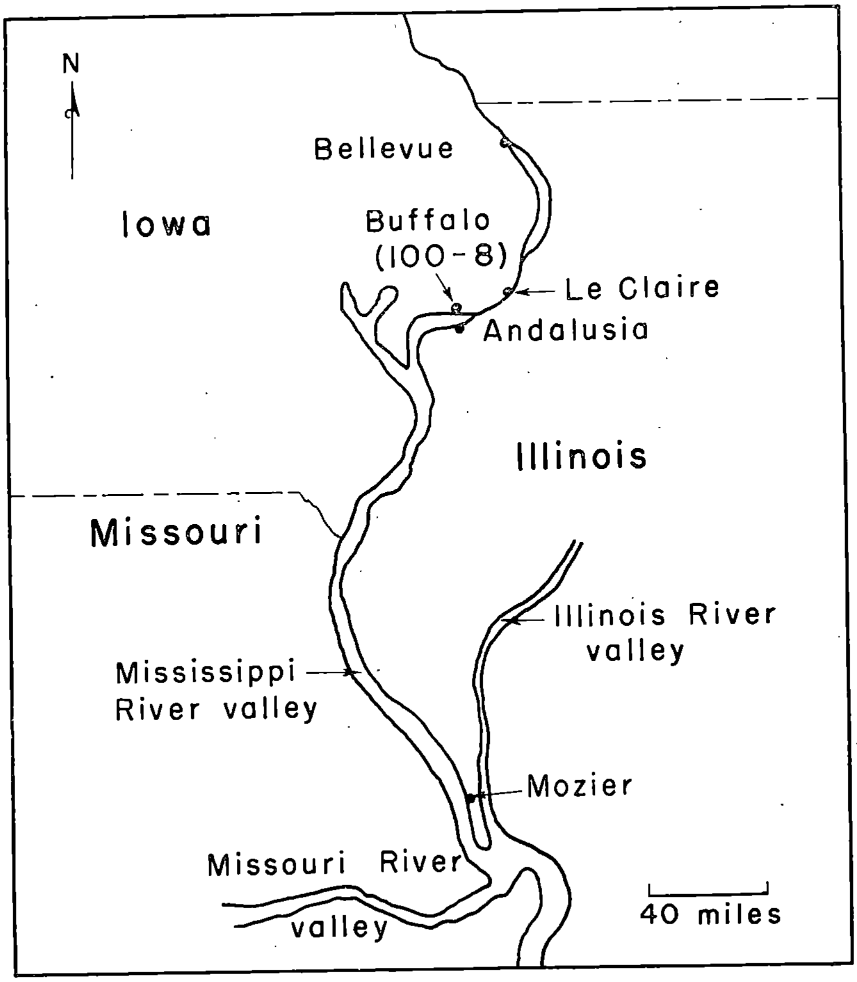

Fig. 12. Sketch map showing locations of samples used for the thermal curves in figure 13.

CONCLUSIONS

Some of the conclusions drawn from this study are as follows:

1. Particle-size data along two traverses indicate a more pronounced relationship of deep, friable loess to the Iowa River than to the Iowan drift border.
2. Deep, friable loess near the Mississippi floodplain is of very limited extent on the Iowa side of the river, and contains appreciable amounts of dolomite. The dolomitic nature of this loess makes it unique from other loess studied in east-central Iowa and southwestern Iowa. Dolomite is in Wisconsin loess near the Mississippi River floodplain as far south as Vicksburg, Mississippi.
3. Engineering properties of the loess depend mainly on clay content. Most of the C-horizon loess in east-central Iowa classifies as A-6 by the Bureau of Public Roads system. The deep loess which usually occurs near the major river valleys commonly classifies as A-4.
4. The influence of soil profile development commonly extends to depths of over 5 feet in the loess. The B-horizon material, which constitutes a major portion of the soil profile, usually classifies as A-7-6.

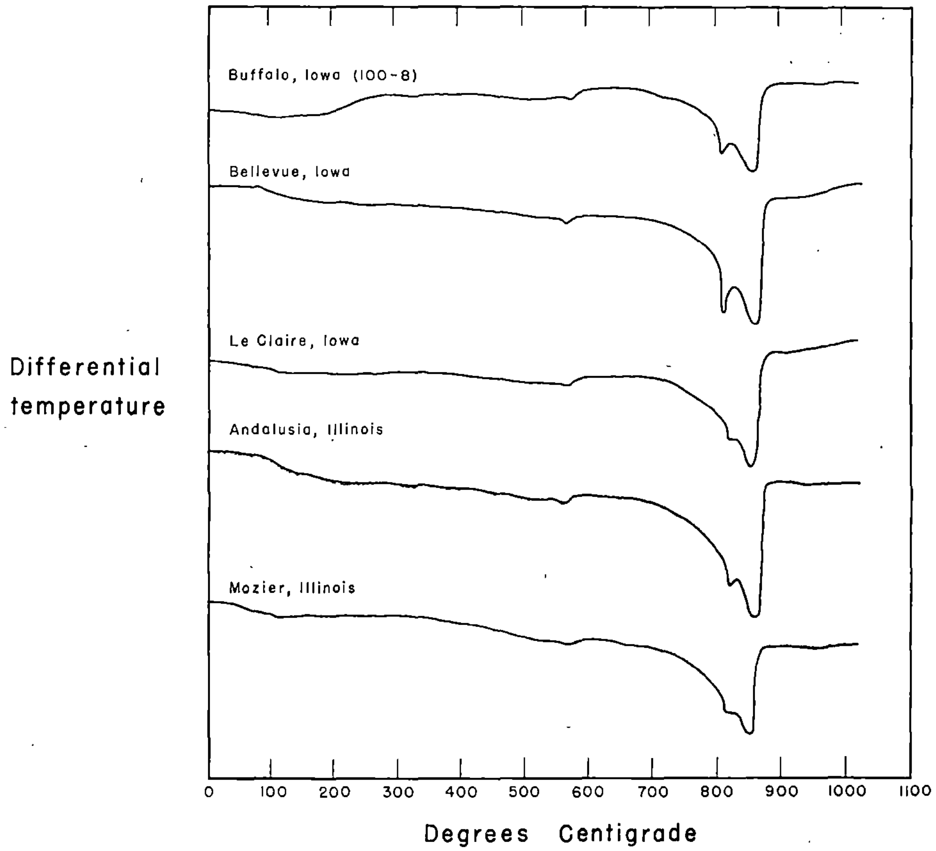

Fig. 13. Thermal curves of loess samples taken within one-half mile of the Mississippi river flood plain.

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COMPARISONS OF PETROGRAPHIC AND ENGINEERING PROPERTIES OF LOESS IN SOUTHWEST, EAST-CENTRAL, AND NORTHEAST IOWA

by

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(Iowa Academy of Science Proceedings 62:279-297. 1955)

The first phase of property studies of loess from three areas in Iowa, Southwest, East-Central, and Northeast Iowa (figure 1) was to sample the loess and determine properties and property variations within each area (table I). Combinations of grid patterns and traverses were used to lay out the sample locations, and samples were taken at various depths at many locations (table II). Systematic areal variations were revealed, and with a grid sampling system it was found that contour lines could be drawn for various loess properties.

The second phase of the research was to select a few C-horizon loess

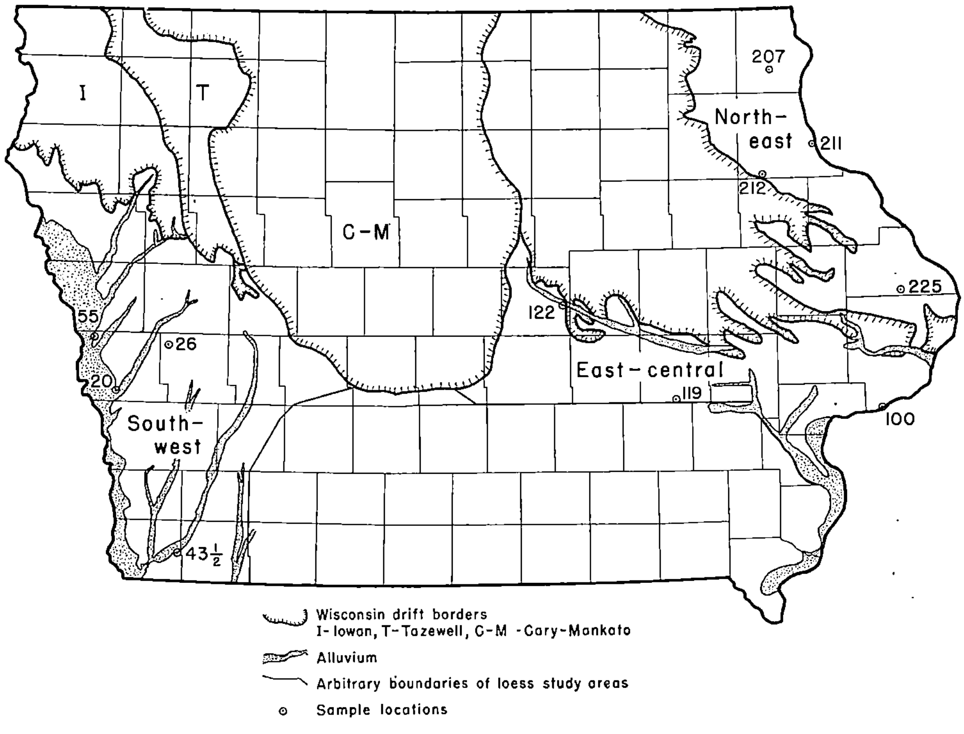

Fig. 1. Map of Iowa showing sample locations in three loess areas.

TABLE I. LOESS SAMPLES SELECTED FOR DETAILED STUDY.
(Leached, moderately plastic samples, are 26-1, 43½-1 and 119-5 in the upper right.)

Area	Samples			
SW Iowa	55-1 A very friable loess, Bignell in age, from the deep loess area adjacent to the Mo. R. flood-plain.	20-2 A typical friable loess of the deep loess area adjacent to the Mo. R. flood-plain. Here the total loess thickness is over 100 ft.	26-1 A typical medium-textured loess. Part of the section, including the sample, is leached from the surface. Total loess thickness, 30-40 ft.	43½-1 A typical plastic loess. Total loess thickness, 15-20 ft. Leached throughout.
E-Cent. Iowa	100-8 A very friable loess representing limited areas of deep loess W. of and adjacent to the Miss. R. floodplain. Total loess thickness, 38 ft.	122-6 A coarse, friable loess representing deep deposits near the Iowa River floodplain. Total thickness, 50 ft	119-5 A typical plastic loess. Total thickness, 10 ft. Leached throughout.	
NE Iowa	211-7 A friable loess from deep deposits near the Miss. R. floodplain. Total thickness, 25.5 ft.	225-5 A friable loess from the south-central part of the area. Total thickness, 12 ft.	207-5 A moderately friable loess from the north-central part of the area. Total thickness, 12.5 ft.	212-5 A moderately friable loess from deep deposits near the Iowan drift border. Total thickness, 18.5 ft.

TABLE II. LOCATIONS OF THE LOESS SAMPLES

Area	Sample No.	Sampling Depth, ft.	Location
SW Iowa	55-1	2½-3¼	Harrison Co. T81N, R44W. SW/c Sec. 8.
	20-2	39-40	Harrison Co. T78N, R43W. NW¼ NE¼ Sec. 15.
	76-1	4-5	Shelby Co. T81N, R40W. SW¼ SE¼ Sec. 21
	43½-1	5-6	Fremont Co. T68N, R40W. NW/c Sec. 36.
E-Central Iowa	100-8	25-25½	Scott Co. T77N, R2E. N½ SW¼ Sec. 13.
	122-6	14-14½	Marshall Co. T83N, R17W. NE¼ SE¼ Sec. 3.
	119-5	6-6½	Iowa Co. T78N, R10W. NE¼ NW¼ Sec. 31.
NE Iowa	211-7	17¼-18¼	Clayton Co. T92N, R2W. SE¼ SE¼ Sec. 6.
	225-5	10-10½	Jackson Co. T84N, R4E. SW¼ SE¼ Sec. 19.
	207-5	10-10½	Allamakee Co. T97N, R5W. NE¼ SE¼ Sec. 23.
	212-5	12¼-12¾	Clayton Co. T91N, R5W. SE¼ SW¼ Sec. 27.

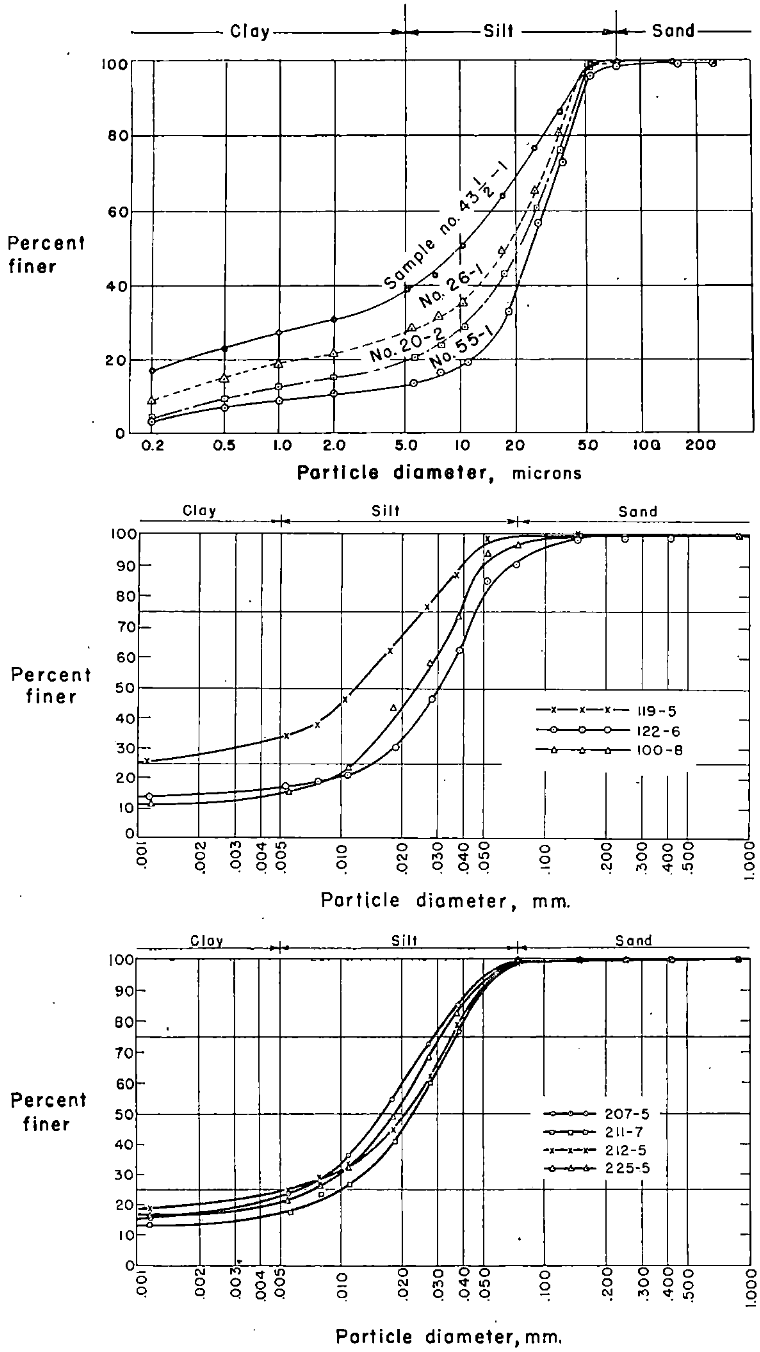

Fig. 2. Particle-size accumulation curves for loess samples from three areas. Top, SW Iowa; center, E-C Iowa; bottom, NE Iowa.

samples for detailed petrographic and engineering study. These samples were carefully chosen as representative of the loess in each of the three areas. Since the loess varies within an area, samples were selected to represent the range in variations. In the preliminary studies, various loess properties were found to be related; for example, plasticity is proportional to clay content. Therefore, samples for detailed study were checked to see that their properties were consistent with these relationships.

Samples were checked to make sure that the measured properties were average for the ranges represented. In addition, the special samples were so selected as to be spread out geographically. This was done that any hitherto unrecognized variations across an area might be recognized. Geographic separation was partly automatic, since loess properties vary systematically over an area, and samples had to be separated to represent varia-

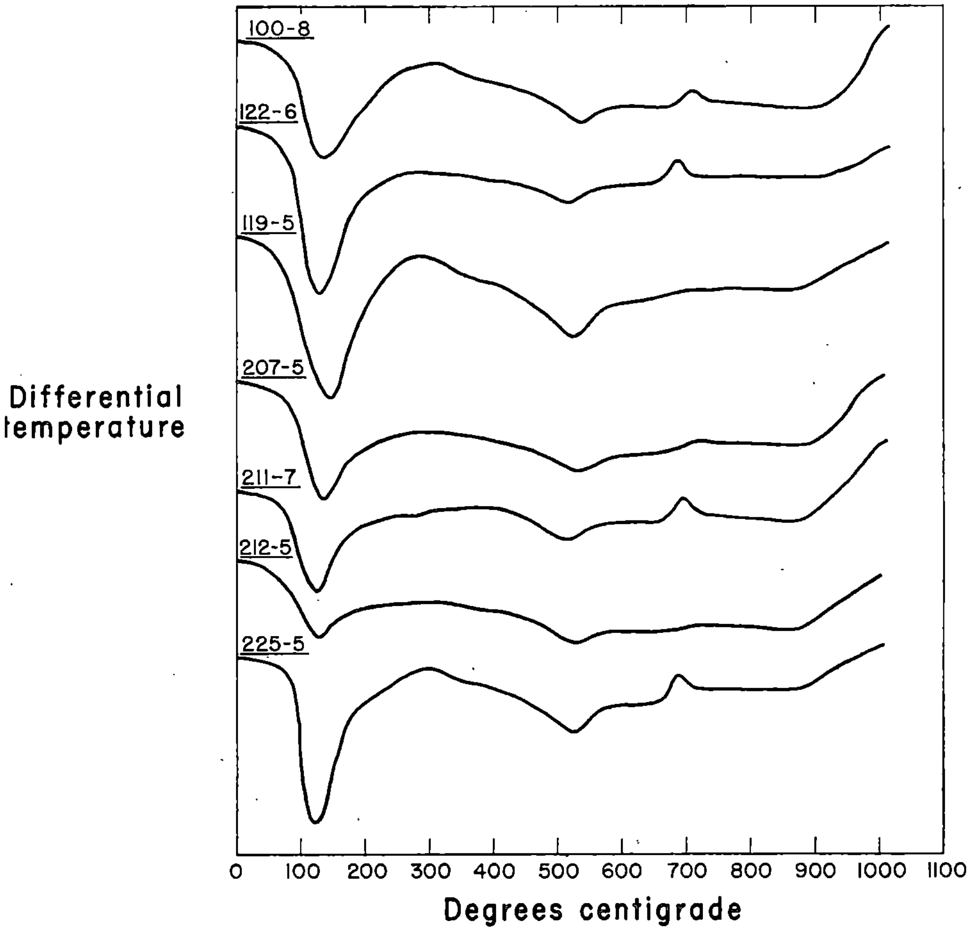

Fig. 3. Differential thermal analysis curves for -2μ clay fractions. Prehumidity, 50% Exothermic peaks at 700° are unexplained.

tions within an area. The selection was in part subjective in that sample locations were chosen to determine the effects of possible different source areas.

PETROGRAPHY

Particle Size.

Particle-size accumulation curves for the selected loess samples show that one southwest Iowa sample is moderately high in clay; all other samples are medium or low in clay (figure 2). Low clay contents are believed to indicate nearness to a source area. Low-clay samples are from near the Missouri, Iowa, or Mississippi rivers. Also selected was a medium-clay sample from near the Iowan drift plain. Particle-size curves show no uniqueness that would indicate from which of the three study areas any sample had come.

Clay Composition.

Clay mineral compositions were interpreted from differential thermal analysis, X-ray diffraction, cation exchange capacity, and staining. Clay minerals in the various loess samples are believed to be essentially the same. The common clay minerals appear to be an intimate mixture of montmorillonite and illite, with montmorillonite predominating. X-ray data show a low, non-uniform glycol expansion suggestive of interlaying. Due to limitations in the methods, accurate quantitative comparisons of typical D.T.A. curves and X-ray spectrometer curves cannot be made (figures 3, 4).

Silt and Sand Composition.

Grains larger than 5 microns (0.005 mm.) were separated into size fractions and examined microscopically (table III).

The loess samples from northeast Iowa are distinctively low in feldspar. In east-central and southwest Iowa, feldspar contents overlap (figure 5). One sample contains almost 10 percent more feldspar than any other; this sample is from one of the few locations of Iowa loess which has been identified as Bignell in age[4].

Perhaps one of the best criteria for recognition of southwest Iowa loess is the minor amount of volcanic glass. Samples from east-central and northeast Iowa had none.

Another strong difference between samples from the three areas was noted:

Northeast Iowa samples usually have more dolomite. The one exception is a high dolomite sample from east-central Iowa (100-8) adjacent to the Mississippi River floodplain. It is believed that the dolomite may reflect probable source areas[2].

A more detailed breakdown of the mineralogical compositions is given elsewhere[2,3]. Orthoclase is the dominant feldspar, with traces of plagioclase

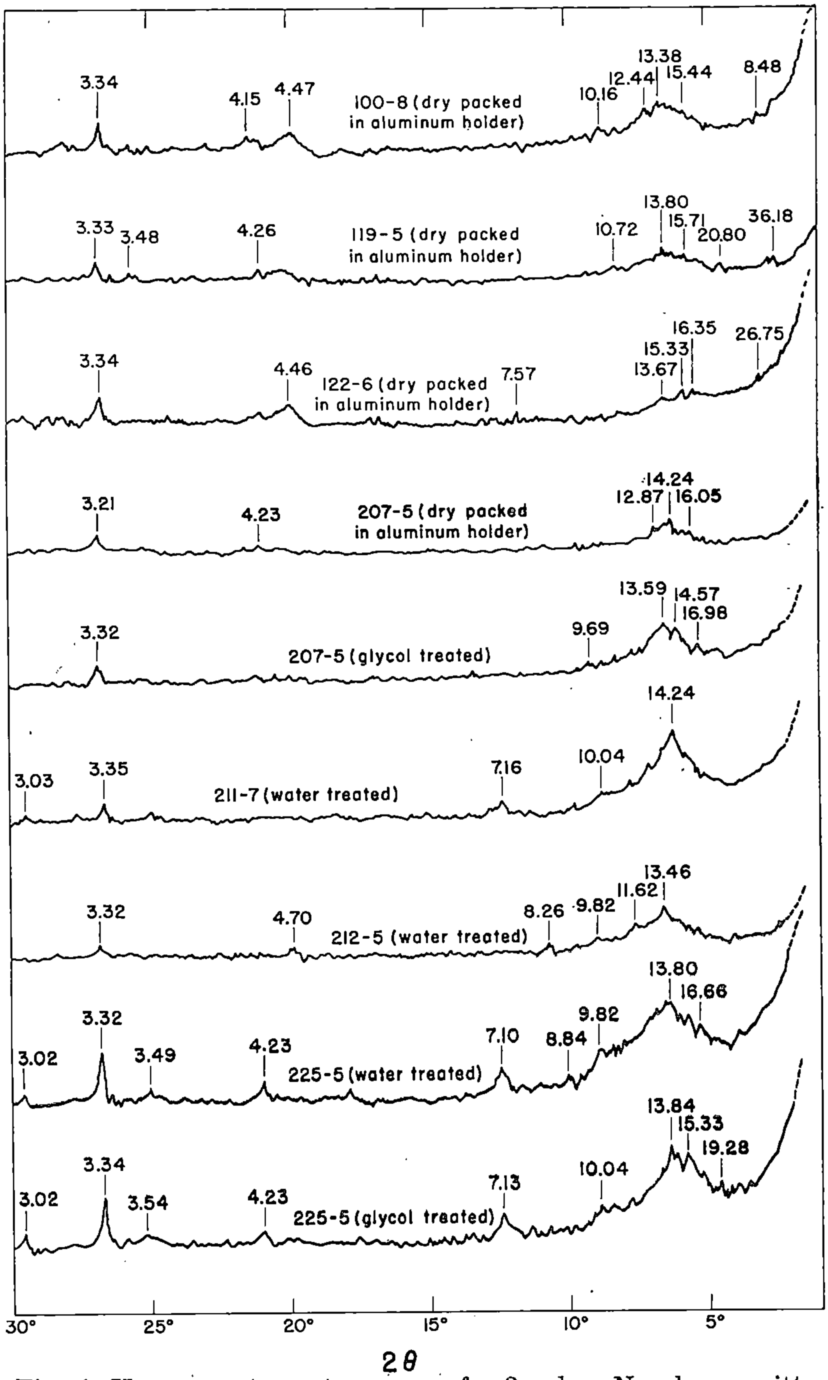

Fig. 4. X-ray spectrometer curves for 2μ clay. Numbers written over the reflections indicate Angström spacings.

and microcline usually present. Muscovite is the principle mica; some biotite also occurs. Amphiboles, pyroxenes, and iron oxides dominate among the heavy minerals.

TABLE III. COMPOSITIONS OF LOESS SAMPLES

Area	SW Iowa				E-Central Iowa			NE Iowa			
Sample No.	55-1	20-2	26-1	43½-1	100-8	122-6	119-5	211-7	225-5	207-5	212-5
Sand and Silt, >5μ											
Quartz	41.1	45.0	48.1	45.0	45.2	49.4	50.3	53.8	51.6	50.3	52.8
Dolomite	1.3	1.1	------	------	5.3	1.1	------	2.4	1.8	2.5	1.8
Feldspar	25.7	17.1	15.8	15.0	16.6	17.1	12.0	8.9	7.5	6.8	6.9
Calcite	7.9	10.7	0.9	0.3	15.3	11.7	0.3	12.0	13.4	13.1	8.8
Mica	0.9	0.7	1.6	1.3	0.3	0.2	0.5	2.0	1.8	1.2	1.9
Volcanic Glass	1.8	1.4	0.8	0.4	------	------	------	------	------	------	------
Heavy Minerals	5.6	4.9	4.0	3.1	4.6	4.4	5.1	3.4	2.9	3.2	2.4
Others	0.4	0.4	1.1	0.5	1.3	0.5	0.3	0.5	0.4	0.4	1.0
Clay, <5μ	13.0	20.0	27.8	39.0	12.0	15.8	32.0	17.0	20.6	22.5	24.4

TABLE IV. AVERAGE SPHERICITIES OF SILT GRAINS IN LOESS SAMPLES.

Area	Sample No.	Average Sphericity*
SW Iowa	55-1	0.76
	20-2	0.76
	26-1	0.76
	43½-1	0.77
E-Central Iowa	100-8	0.76
	122-6	0.76
	119-5	0.76
NE Iowa	211-7	0.79
	225-5	0.77
	207-5	0.79
	212-5	0.78

* Sphericity $= \frac{\text{Intermediate Diameter}}{\text{Maximum Diameter}}$

Sphericity and Roundness.

The averages of loess grain sphericites in various samples are remarkably uniform, but sphericites tend to be slightly higher in northeast Iowa (table IV). These samples are also lower in feldspar. All sphericity histograms are slightly skewed towards the right (figure 6). The reason for this is not known.

Surface Area.

Since compositions were determined in each size fraction, surface areas may be calculated. Spherical grain shapes are assumed; since the average sphericity is nearly constant, the error in different samples should be practically constant. The surface areas of various minerals should be more important for chemical stabilization than are the actual mineral percentages (figures7, 8). Surface areas are higher in finer sizes (table V).

Chemical Tests.

Cation exchange capacity, which is one of the best indicators of clay minerals, is plotted against clay content (figure 9). The southwest Iowa and northeast Iowa samples show the same relation to clay percentage, indicating a probable similarity in clay mineral composition. The east-central Iowa cation exchange capacities are low and do not fall on the same

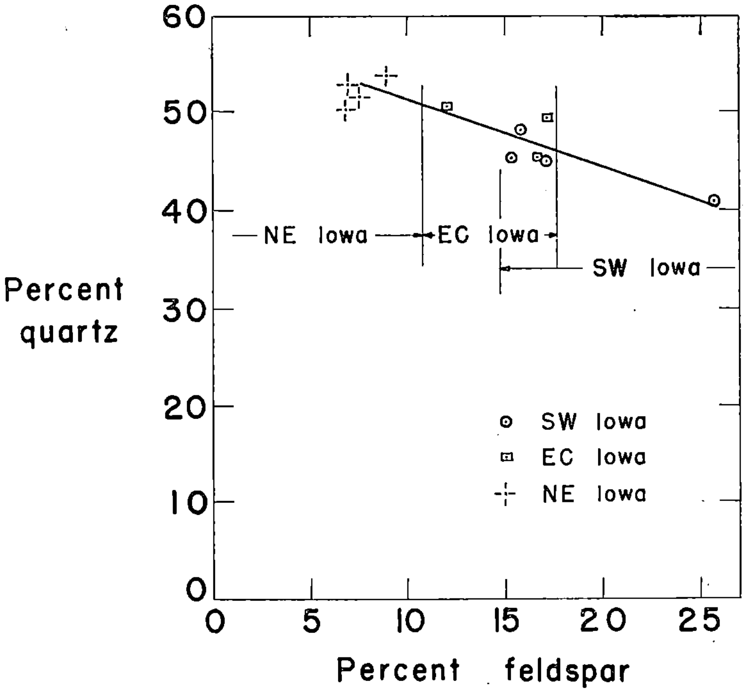

Fig. 5. Feldspar and quartz percentages for loess in Iowa.

straight line. This may indicate less montmorillonite and more illite in the east-central Iowa samples.

Chemical determinations of organic matter show less than 0.2 percent in most samples. Sulphates and chlorides are only in trace amounts. The free iron content is usually less than one percent. The pH of calcareous loess is slightly basic; the pH of leached loess is near neutral. These data are practically the same for samples from all three areas—no differences are shown.

ENGINEERING PROPERTIES

Prediction with Soil-Cement.

Studies with soil-cement have indicated that reactivity of southwest Iowa loess may be related to quartz surface area[3]. Also, reactivity appears to be greatly reduced by clay, probably because much of the clay occurs as coat-

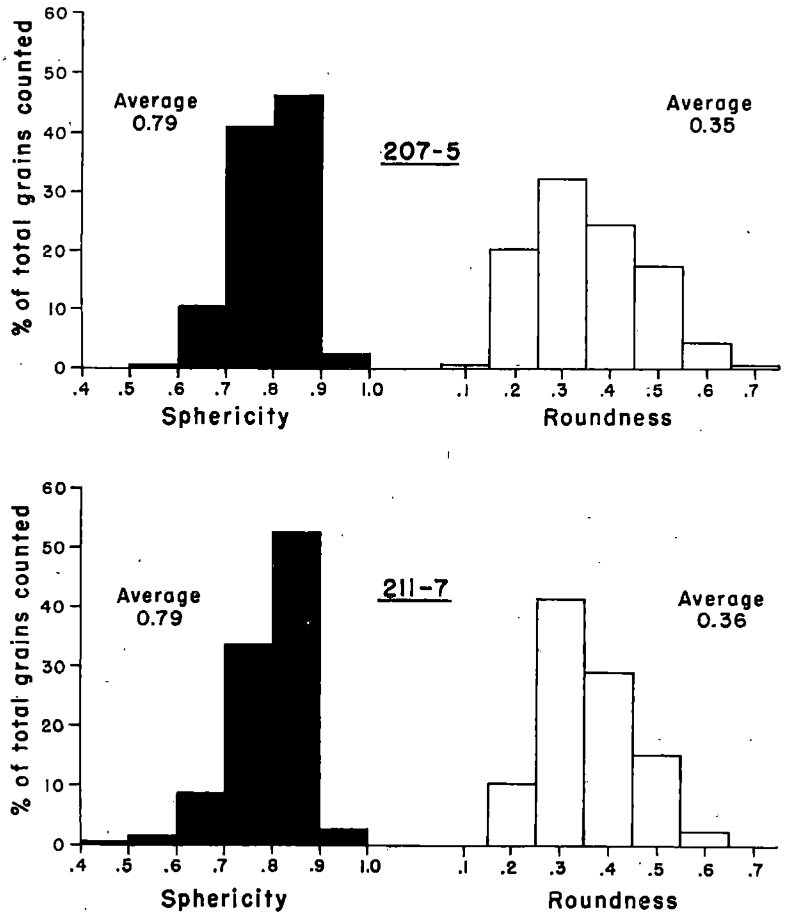

Fig.6. Histograms showing grain sphericity and roundness in two loess samples.

ings on the silt grains. An empirical (and tentative) Reactivity Index was devised to express these two relationships (table VI). Reactivity was indicated by large strength gain through a severe weathering test. From table VI, it would be expected that most of the loess in northeast Iowa

TABLE V. CALCULATED NON-CLAY MINERAL SURFACE AREAS IN THE LOESS SAMPLES, SQ./CM/GM

	SW Iowa				E-Central Iowa				NE Iowa		
Sample No.	55-1	20-2	26-1	43½-1	100-8	122-6	119-5	211-7	225-5	207-5	212-5
Quartz	410	502	520	647	552	407	588	549	584	669	516
Feldspar	241	177	187	236	218	170	167	96	94	81	85
Calcite	81	110	11	8	218	138	7	153	200	206	118
Dolomite	16	12	----	----	56	10	----	25	22	33	22
Volcanic Glass	21	12	9	4	----	----	----	----	----	----	----
Heavy Minerals	53	42	62	62	56	42	78	36	34	43	28
Mica and Others	10	7	23	11	30	9	14	22	29	18	28
Total	842	862	812	968	1130	776	854	881	963	1050	797

TABLE VI. POSSIBLE SOIL CEMENT REACTIVITY OF VARIOUS LOESS SAMPLES

Sample No.	Area	Calculated Reactivity Index*	Known Reactivity†
207-5	NE	555	
100-8	E-Cent.	535	
211-7	NE	500	
225-5	NE	497	
20-2	SW	422	Reactive
55-1	SW	388	Somewhat reactive
212-5	NE	371	
122-6	E-Cent.	368	
26-1	SW	306	Very slightly reactive
119-5	E-Cent.	261	
43½-1	SW	54	Not reactive

* RI=Spec. Surf. (in sq./cm/gm)—0.01 x (clay content)[3].
† Indicated by strength **gain** during severe weathering tests.

would be reactive, and the localized dolomitic loess deposits in east-central Iowa along the Mississippi River would be reactive. Further research with soil-cement should show if it is true.

Plasticity.

Plasticity is related in part to clay content (figure 10). A-6 and A-7-6 C-horizon samples are only found away from the major rivers. The A-6 sample from northeast Iowa was taken adjacent to the Iowan drift border, but not near any major outwash stream. Near large rivers the loess is usually the more friable A-4.

Proctor Density; C.B.R.

The Proctor density is the soil density obtained with a standard compactive effort. An optimum moisture content gives a maximum Proctor density which appears to be related to sand content, particle shape, and clay. The optimum moisture is increased by an increase in clay, due to water retention by the clay. Samples low in clay have a very critical optimum moisture content, probably due to the uniform particle size.

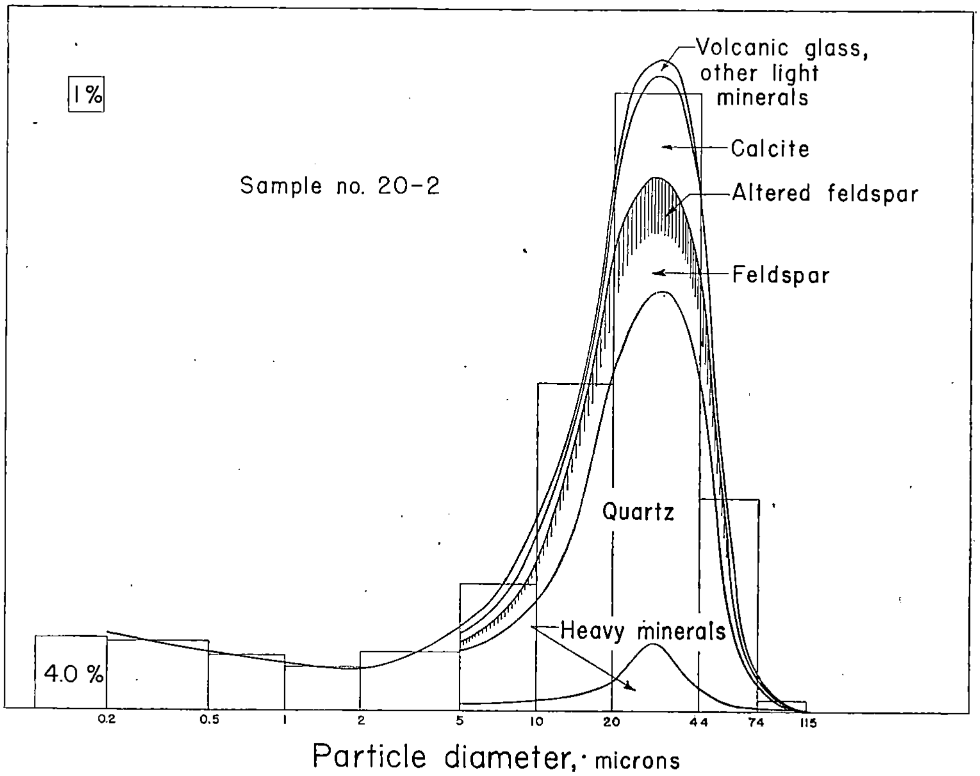

Fig. 7. Diagram showing percentages of minerals in various size fractions of a loess sample.

The California Bearing Ratio, penetration measurement of compacted soil, is expressed as a percent comparison with rolled stone. C.B.R. values are related to the compacted density (figure 11). The highest C.B.R. value is for an east-central Iowa sample (122-6) containing about 10 percent fine sand. This sample also has a high C.B.R. after soaking. The second highest value is for a northeast Iowa sample (225-5) with almost no sand and moderate clay. This sample compacts to a higher density than a southwest Iowa sample (20-2) with the same percent of clay, and it does so with less moisture. The southwest Iowa sample is consistently coarser and contains slightly less clay—yet it has a lower C.B.R. None of a number of possible explanations seems to apply consistently to all samples. In fact, wide variations have been found in the compactibility of different batches of sample 20-2. The size gradation curves show no wide variations. The only relatively unmeasured variable is the clay. Two things are not known about the clay,

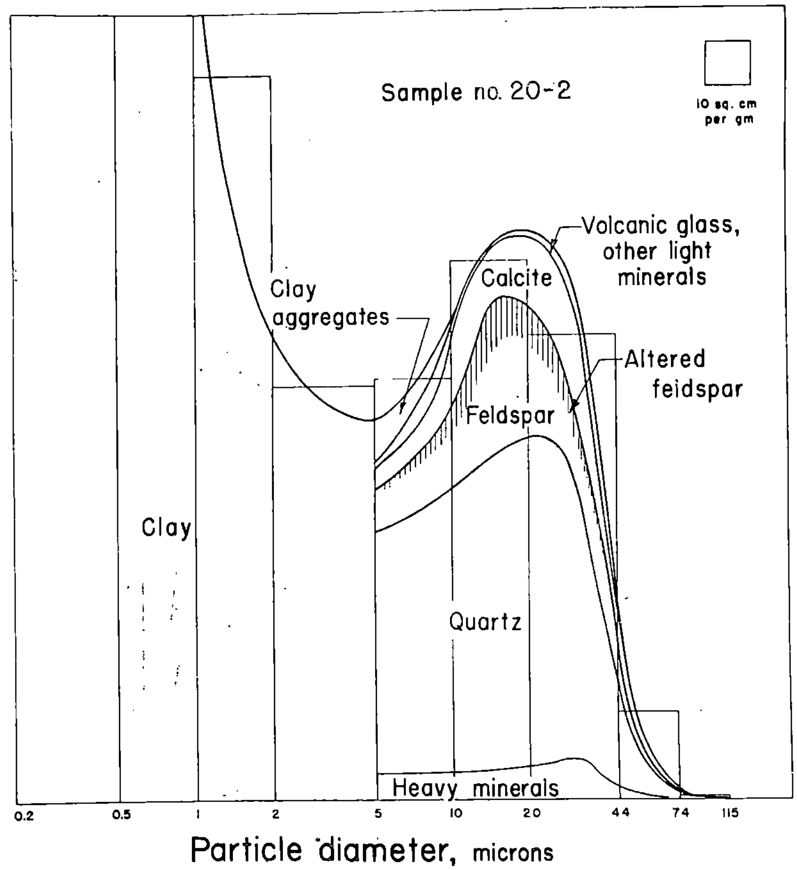

Fig. 8. Diagram showing surface areas of minerals in various size fractions of a loess sample.

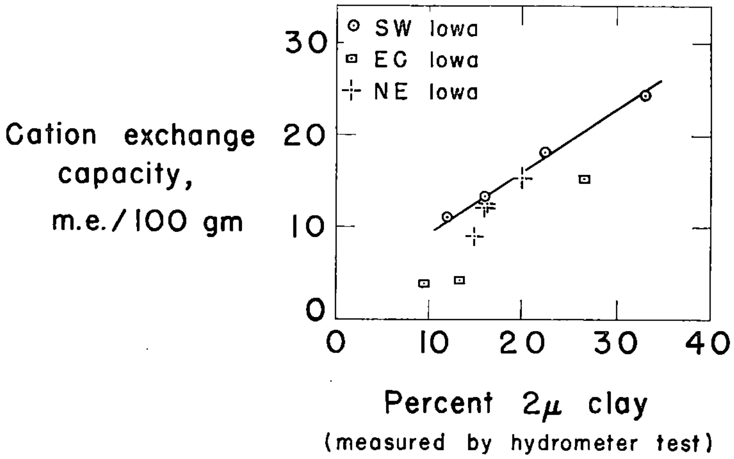

Fig. 9. Cation exchange capacity of whole loess samples related to their clay content.

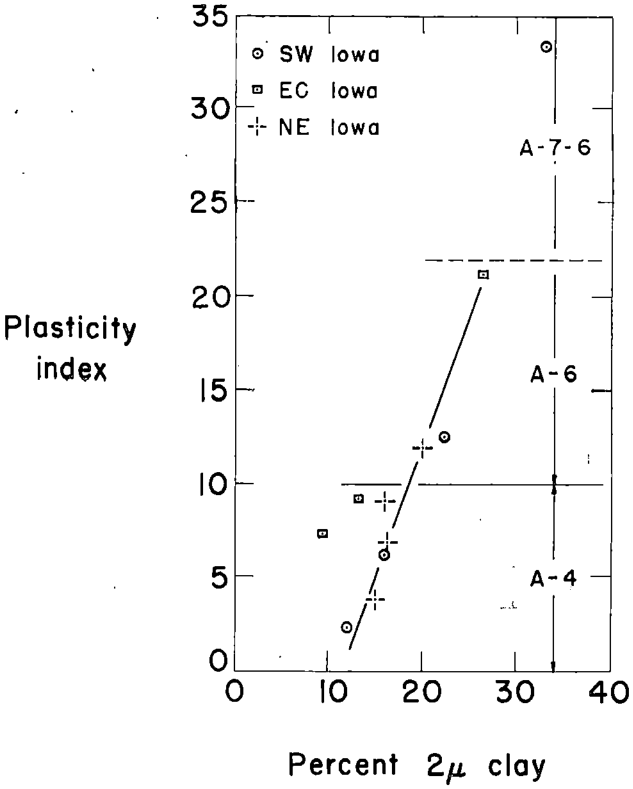

Fig. 10. Plasticity index related to clay content. An engineering soil classification of the samples is shown at the right.

an accurate, quantitative determination of mineralogical composition, and an accurate measure of how the clay occurs in the loess—whether as particles, aggregates, or as coatings.

Clay-silt relationships have been noted and visually estimated with the use of the microscope for some of the samples. In general, most of the clay grains adhere to the larger silt grains, and partially coat them. Estimates of percent coverage ranged from 15 to 40 percent for various samples, the higher values being for samples higher in clay. Superficial examinations indicate that northeast Iowa samples with the exception of No. 211-7 have a higher percentage of clay coatings than do southwest Iowa samples with the same percent clay. The clay may serve as lubrication, allowing more compaction, or it may aid cohesion. Thus 225-5, with the same percent clay as 20-2, appears to have more clay as coatings, possibly making com-

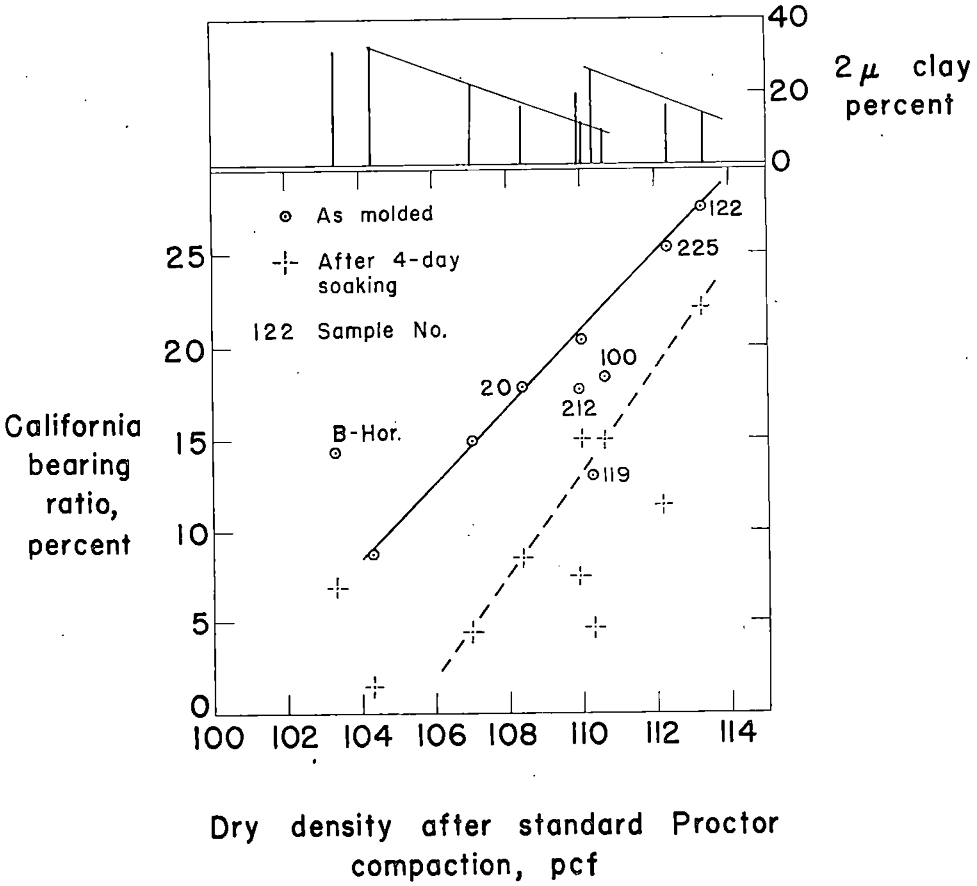

Fig. 11. California Bearing Ratio related to compacted density. There are two points for each sample, since the C.B.R. is lowered by soaking. Graph at the top shows the clay content of each sample.

paction easier and giving a higher C.B.R. It should be noted that 225-5 shows a much greater loss of C.B.R. on wetting.

Other anomalies are as difficult to explain (figure 11). Samples 119 and 212, high in clay, compact to a high density but have a low C.B.R. Is this due to a higher clay occurrence as coatings? One B-horizon sample high in clay compacts to a low density but has a relatively high C.B.R. More clay as aggregates, less as coatings? These questions cannot be easily answered, especially since standard methods of mechanical analysis are designed to destroy the natural aggregation of the clay. It is apparent that new methods are needed if the C.B.R. is to be estimated.

CONCLUSIONS

1. No unusual features of particle-size were found which would show from which of the three study areas any sample had come.

2. Clay mineral compositions qualitatively are believed to be the same. The principal clay minerals appear to be an interlayered mixture of montmorillonite and illite. Quantitative differences have not been measured.

3. Compositions of loess, silt, and sand show three distinctive features:

a. Northeast Iowa samples are distinctively low in feldspar, running from 5 to 10 percent. The single Bignell loess sample is high in feldspar, containing 25 percent. East-central samples and other southwest samples are in between.

b. Southwest Iowa loess samples contain volcanic glass. Northeast and east-central Iowa samples do not.

c. Northeast Iowa samples contain slightly more dolomite than do other samples. The one exception from near the Mississippi River is an east-central Iowa sample which is very high in dolomite.

4. Sphericities of various samples are very nearly the same but tend to be slightly high in northeast Iowa, perhaps because of the lower percentage of feldspar and the higher percentage of quartz.

5. Cation exchange capacity is related to clay content. East-central Iowa samples have a low cation exchange capacity relative to their clay content. They, therefore, may contain less montmorillonite. This is the only indication of a clay difference.

6. Silt mineral surface areas have been calculated, and on the basis of an empirical formula, predictions have been made for soil-cement. The predictions may not be valid due to uncertain effects of the clay (see below). If they are valid, northeast Iowa samples and the dolomitic east-central Iowa sample should react well in soil-cement.

7. The California Bearing Ratio is usually related to compacted soil density. Almost identical samples were found to be widely variant in compaction. This and other C.B.R. anomalies cannot be explained without a difference in clay. Partial observations indicate that this may be largely a difference in disposition of the clay rather than a difference in clay mineral.

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VARIATION OF LOESS THICKNESS AND CLAY CONTENT IN SOUTHERN IOWA

by

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(Iowa Academy of Science Proceedings 64:393-399. 1958.)

Some of the locations from which samples were taken for this research were determined by a series of traverses in southwestern Iowa and some by a grid pattern which was carried into south-central and east-central Iowa. Supplemental traverses were used in east-central Iowa. Loess decreases in thickness eastward from assumed sources such as the Missouri River, and the percentage of finer material increases. Although mainly self-explanatory, the following features of the map showing the loess thickness stand out (figure 1):

(1) From the south-central part of the state, the loess thickens toward the western part of the state and toward the Iowa River to the northeast.

(2) Proceeding east from the eastern edge of the Missouri River flood plain, the loess thins at a progressively decreasing rate.

CLAY CONTENT

Features on the tentative contour map showing the percent of minus 5 micron clay and clay-size material in the C horizon of the loess (figure 2) are the following:

(1). The clay content increases generally eastward from the Missouri River, but there is a more distinct trend running southeast from the extreme south-central part.

(2). The 5 micon clay increases southwest from the Iowa River to the same area in extreme south-central Iowa.

(3). The rate of change of clay content varies in different parts of southern Iowa.

It is relatively rapid in the extreme southwestern part of the state; and it is fairly uniform over the rest of southern Iowa except for a band running east-west through the south-central part where the clay content itself is uniform, varying between 35 and 40 percent.

ACCURACY OF MAPS

Because contour control depends on the number of sample locations, both of these maps must be considered as tentative. Another important factor which influences the loess thickness map is the topographic position of the sample sites. The loess is thickest at crests of divides with progressive thinning down the flanks in both an easterly and westerly direction[12]. This

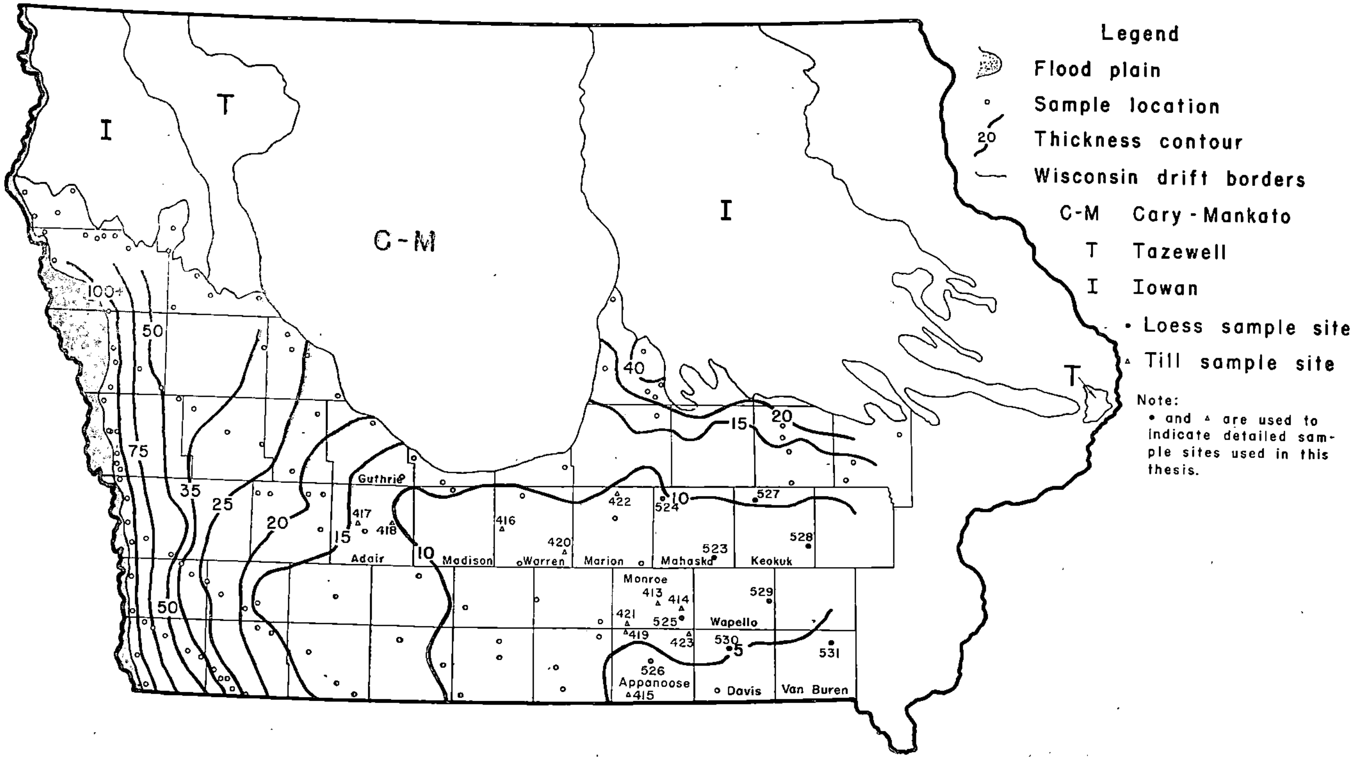

Fig. 1. Tentative map showing areal distribution of Wisconsin loess thickness in southern Iowa.

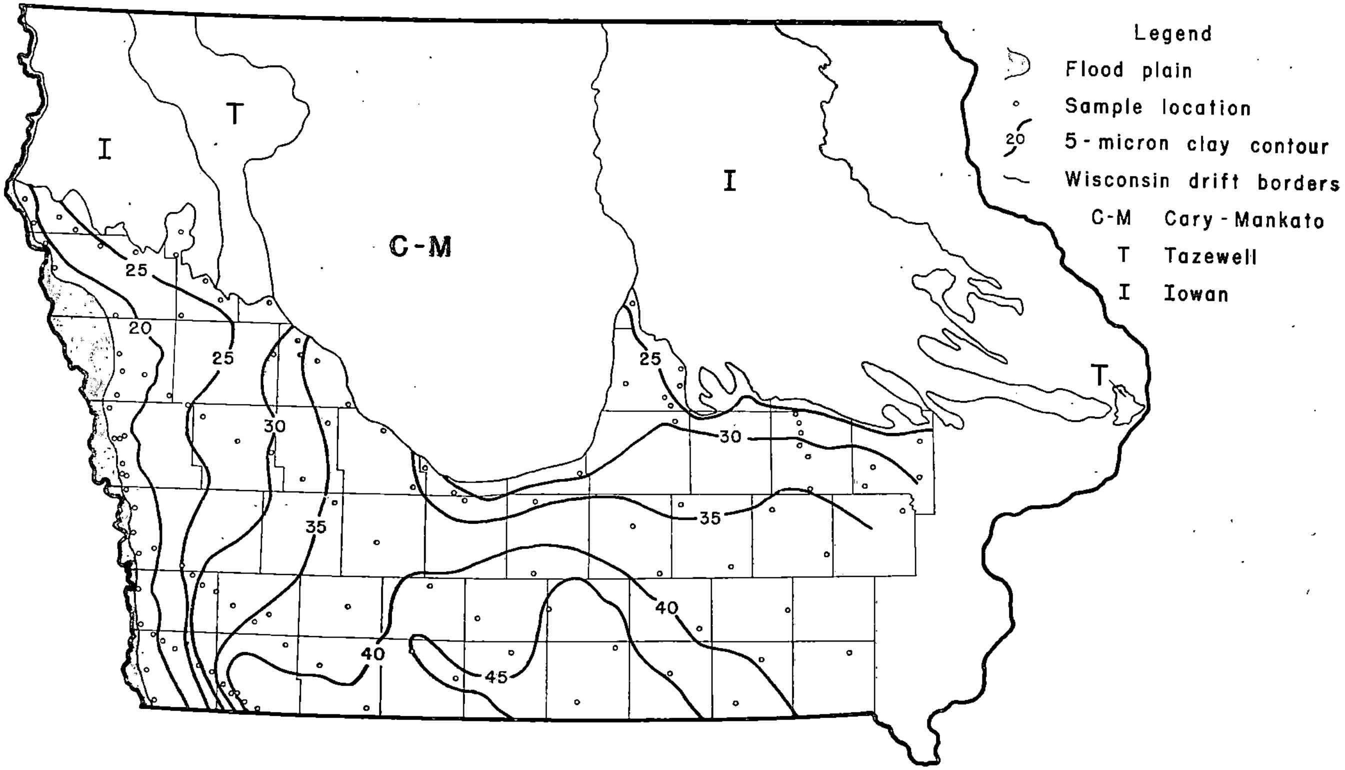

Fig. 2. Tentative map showing areal distribution of 5-micron clay content in the Wisconsin loess of southern Iowa.

relationship is much in evidence in the dissected topography of south-central Iowa where roadcuts exposing the total loess thickness of hills shows a downslope thinning of the loess into the valleys, where erosion has been most severe on the loess mantle.

If all the sample sites had been located at the highest topographic positions (primary divides) as the traverses and grids moved eastward across southern Iowa, the contour map of the loess thickness could be interpreted as representing the maximum loess thickness. If sample locations had been closely spaced down the flanks of divides, one could expect to find decreasing loess thickness away from primary, secondary, and tertiary divides both in an easterly and westerly direction. The contour map (figure 2) shows only the general thinning of the loess eastward from the Missouri River.

The crux of the point is that some of the data on which the loess thickness contours were based were taken not from auger holes located at topographic highs within a given area, but from road cuts on the flanks below the relatively flat interfluvial divides. They therefore do not show the maximum loess thickness in all areas.

PARTICLE SIZE

The composite cumulative curve showing the range of particle size distribution in the C-horizon of seven major loess samples from south-central

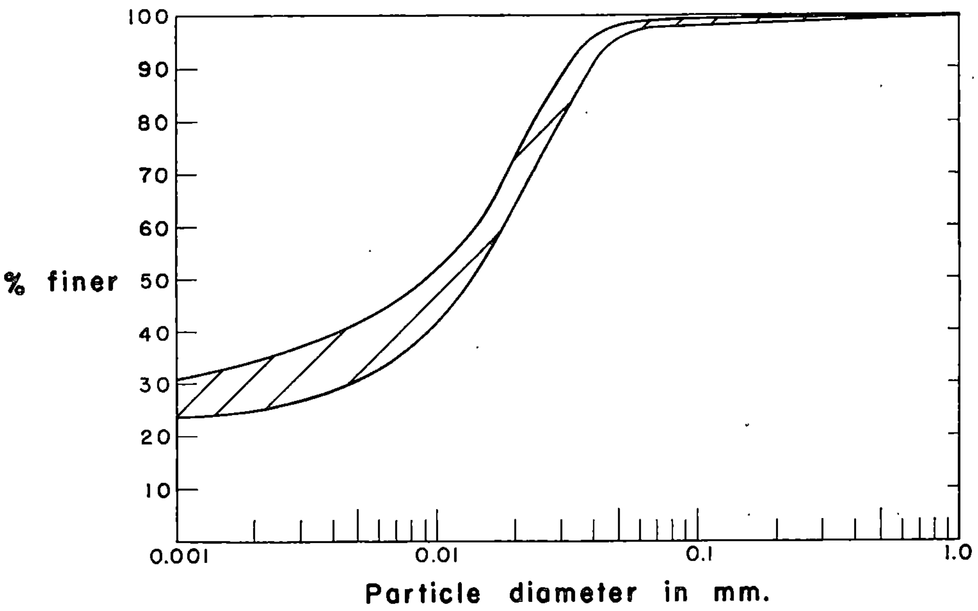

Fig. 3. Composite cumulative curve of the C-horizon of seven major loess samples from south-central and southeast Iowa.

and southeast Iowa (figure 3) indicates that sand percentages vary from 0.5% to 2.0%, or through a range of 1.5%. Silt percentages vary through a range of 11%, and the clay content range is also 11%. In the different loess samples the clay and silt vary inversely with each other, the sand content, mostly iron concretions, remaining relatively constant.

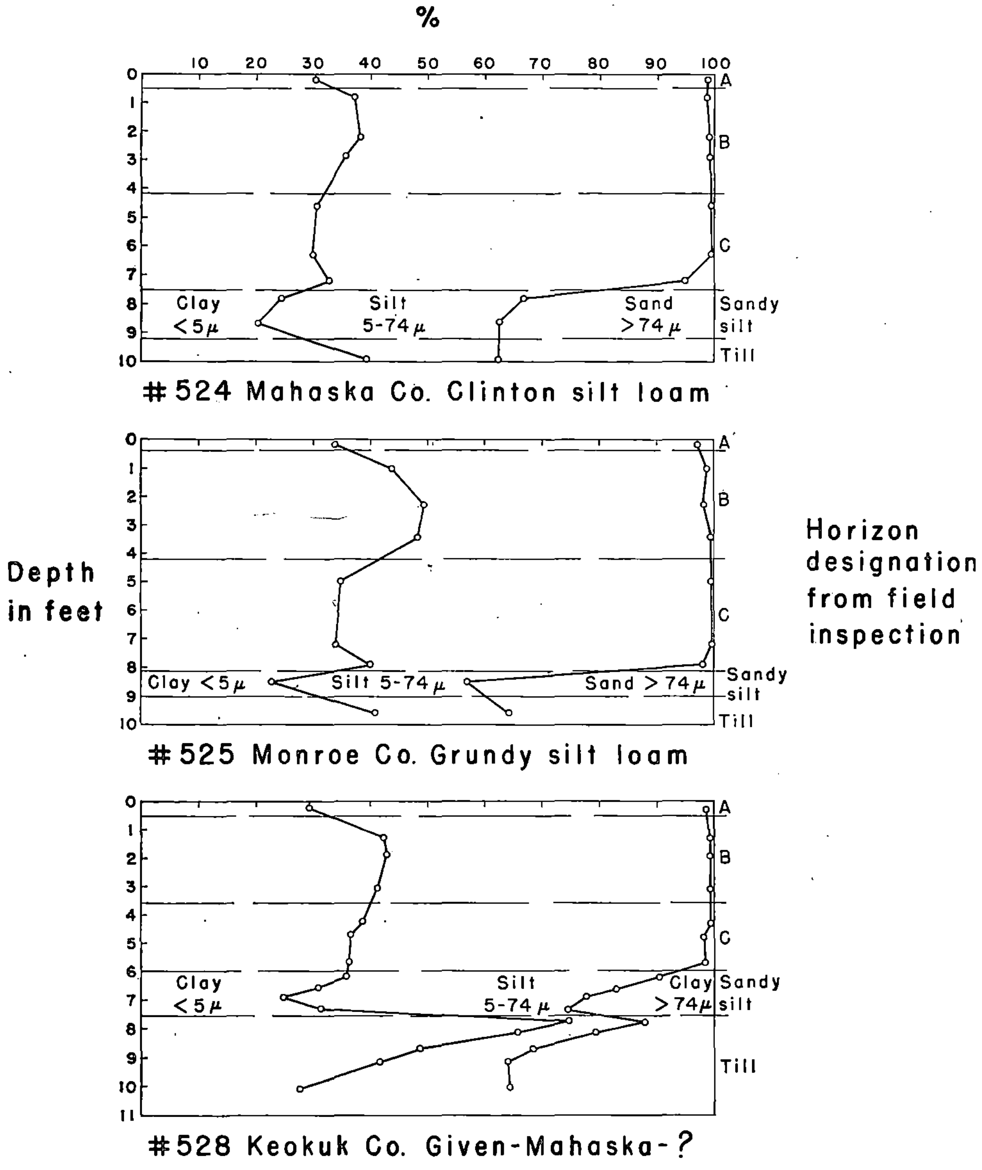

Fig. 4. Distribution of sand, silt, and clay with depth in three profiles from south-central Iowa.

SANDY SILT

In the field work on the loess and till of south-central Iowa the sandy-silt which underlies the loess and overlies the till became of interest. The origin of this sandy-silt has been related to a process of landscape evolution.

In the first two of three profiles from south-central Iowa (Nos. 524 and 525) only one or two samples were taken directly from the sandy-silt (figure 4). In the distribution of sand, silt and clay with depth the contact with the overlying loess is sharp in respect to sand content; and as the sand content increases, the clay content decreases. As more samples were

TABLE I. SAMPLE LOCATIONS (FIGURE 3)

Sample No.	Horizon	Location (County)	Depth
524-5	C-Non-calc.	Mahaska, NW	73"—79"
525-5	" " "	Mahaska, SE	70"—76"
527-6	" " "	Keokuk, NW	62"—68"
528-5	" " "	Keokuk, SE	65"—71"
529-5	" " "	Wapello, E-Center	50"—56"
531-3	" " "	Van Buren, NE	45"—41"
534-5	" " "	Monroe, E-Center	50"—70"

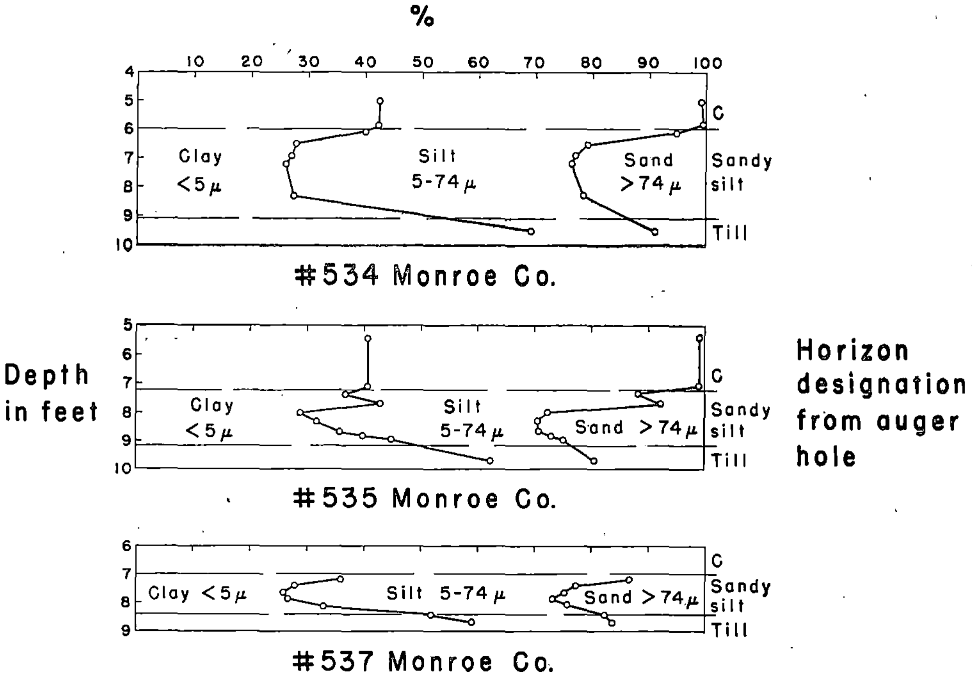

Fig. 5. Distribution of sand, silt, and clay within the sandy-silt with depth in three profiles from south-central Iowa.

taken from the sandy-silt, the detail produced from No. 528 (figure 4) and from the three profiles (figure 5) shows:

(1) The contact between the loess and sandy-silt is sharp.

(2) There now appears to be an inverse relationship between amounts of sand and clay in the sandy-silt; the silt itself is fairly constant. Compared with the inverse relationship between clay and silt in the loess, the sand is fairly constant.

(3) The contact between the sandy-silt and the underlying till is sharp.

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FURTHER STUDIES OF LOESS IN IOWA: THICKNESS, CLAY CONTENT, AND ENGINEERING CLASSIFICATION

by

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(Iowa Academy of Science Proceedings 65:317-322. 1959.)

LOESS THICKNESS

From the tentative map of Wisconsin loess thickness in western, southern, and eastern Iowa (figure 1) it is apparent that two areal distribution patterns in western Iowa are separated by the border between the Iowan-Tazewell and Kansan drift sheets. Loess thickness, significantly greater south of this drift border, reaches a maximum depth of over 150 feet immediately adjacent to the Missouri River floodplain. North of the drift border, adjacent to the Big Sioux River, the maximum depth of the loess is only about 25 feet. Because of the difference in the two areas, no attempt has been made to connect thickness contours.

The loess eastward from the Missouri River floodplain shows a major thinning trend (figure 1). In eastern Iowa in a second thinning trend the loess diminishes to the north and south of a contoured high located near the approximate terminus of the Iowan drift.

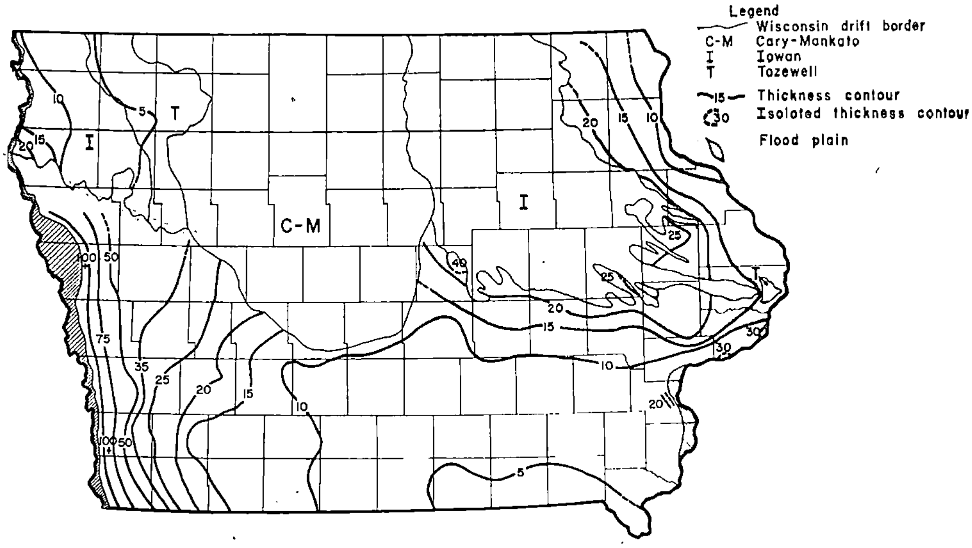

Fig. 1. Map of Wisconsin loess thickness.

CLAY CONTENT

The percent of minus 5 micron clay in the C-horizon loess increases eastward from the Missouri River and is at a maximum in south-central Iowa (figure 2). Analyses were made by the hydrometer method (ASTM Designation D422-54T). Clay content decreases to the northeast from the maximum area by the 45 percent contour, reaching a minimum within the 20 percent contour. North and east of this area, the clay content again increases toward the Mississippi River.

From a comparison of the contours (figures 1, 2), a generalization may be made that as loess thickness decreases, clay content increases (figure 3) [5, 12, 14].

Both the loess thickness and clay content maps must be considered as tentative, although nearly 200 sample sites were analyzed for each. Few samples have been obtained within the area of the Iowan drift east of the Cary-Mankato lobe. Loess thickness varies significantly with respect to topographic position, commonly thining below crests of divides in an east-west direction[12]. Primary consideration was given to data representing sample sites known definitely to be located at or near the crest of topographic highs. Equal importance was attached to sample locations designated or observed to be located on the very flat terrain of the uplands. It is hoped that erosion effects may be reduced by the use of samples so chosen.

ENGINEERING CLASSIFICATION

In classifying the loess for engineering purposes the standards of the

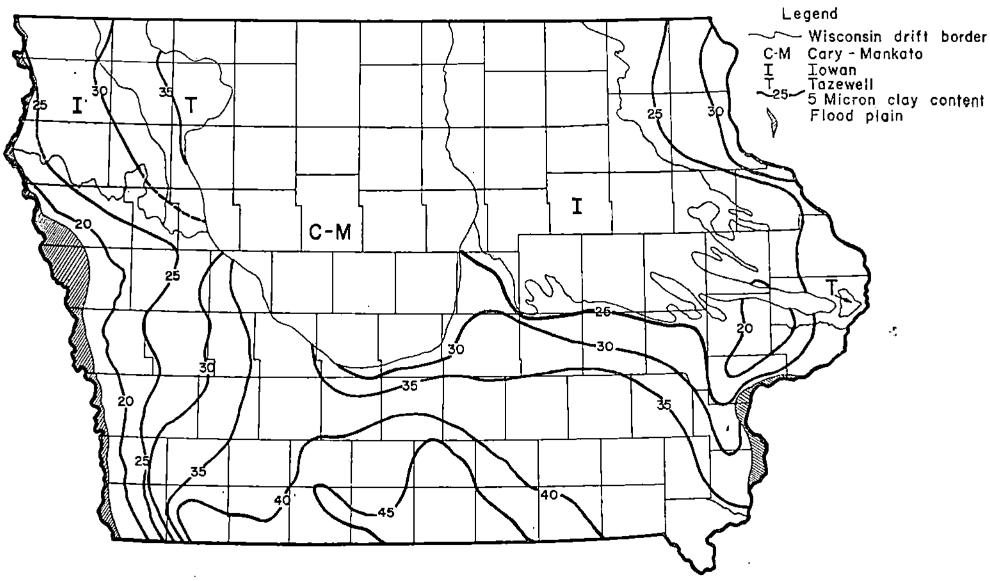

Fig. 2. Map showing clay content of Wisconsin loess.

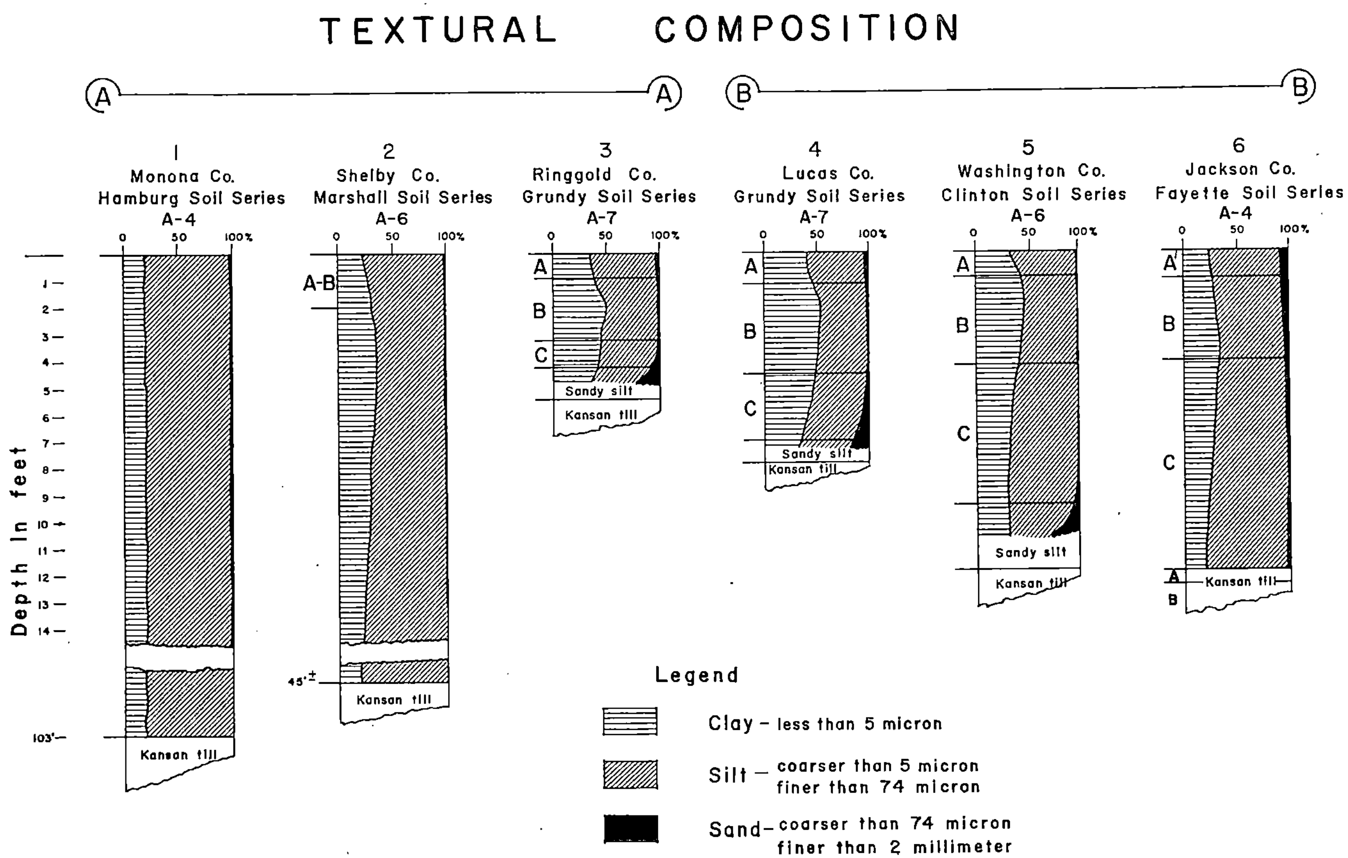

Fig. 3. Textural composition of Wisconsin loess along traverses A-A and B-B. Note increase in clay content with decrease in loess thickness.

American Association of Highway Officials were followed.[1]. Samples representing C-horizon loess were obtained at depths which ranged from around sixty feet near the bluffs bordering the Missouri River flood plain to as little as two to four feet in south-central Iowa.

Seven major soil groups have been proposed by the AASHO, and loess falls into the A-4, A-6, and A-7 groups (figure 4). The general description of the A-4, A-6, and A-7 groups is as follows:

> "*Group A-4.* This group contains nonplastic or moderately plastic silty soil usually having 75 percent or more passing the No. 200 sieve (74 micron). Mixtures of fine silty soil and up to 64 percent of sand and gravel retained on the No. 200 sieve are also included.
>
> "*Group A-6.* Group A-6 contains plastic clay soils usually having 75 percent or more passing the No. 200 sieve. Mixtures of fine clayey soil and up to 64 percent of sand retained on the No. 200 sieve are included.
>
> "*Group A-7.* Plastic clay soils similar to those in Group A-6, but having higher liquid limits, make up Group A-7. The soils may occasionally be elastic as well as subject to high voume changes."

Soils of several major groups are subdivided on the basis of texture, liquid limit, and plasticity index. All groups are further divided by a numerical group index, which places a relative index of performance on individual soils within a group. In this report, only the major group designations are used.

Clay content has a direct relation to plasticity[6, 13]. In western Iowa in

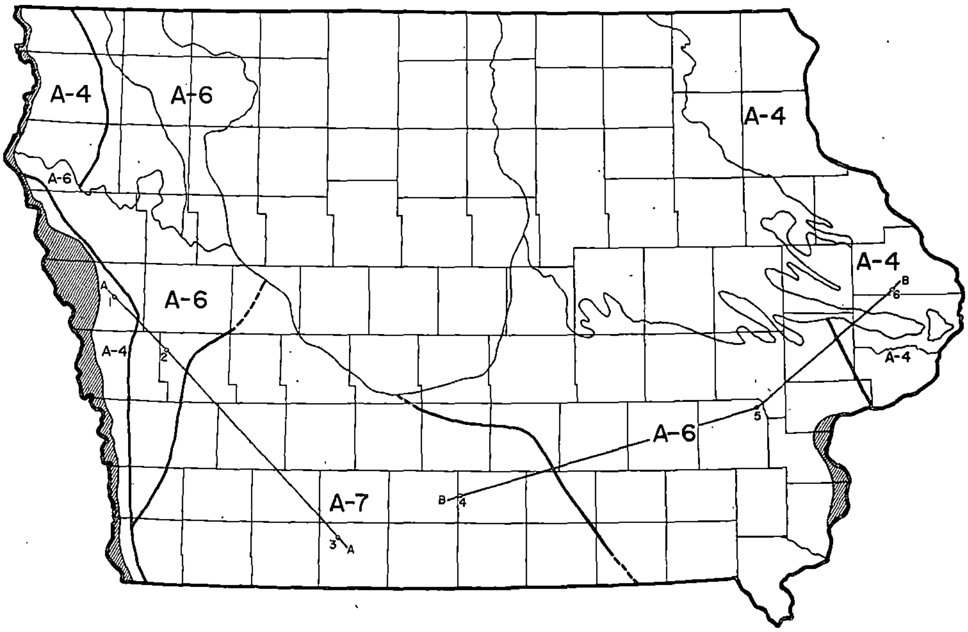

Fig. 4. Engineering classification of Wisconsin loess. Note traverses A-A and B-B.

the narrow band which parallels the flood plain, clay content is 25 percent or less, and the plasticity index of most samples is less than 10. These samples are included in the A-4 group. As clay content increases, the plasticity index usually is greater than 10. This area is shown by the A-6 band. Further east and southeast the clay content reaches a maximum (figures 2 and 3), and liquid limits and plasticity indices are greatest within the area designated A-7. Samples obtained in southeast Iowa indicate a second broad A-6 area extending toward the Mississippi River.

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PETROGRAPHY AND ENGINEERING PROPERTIES OF LOESS AND KANSAN TILL IN SOUTHERN IOWA

by

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C. J. Roy, Professor and Head, Geology Department

(Progress Report, Mimeograph ,September, 1958.)

The study of loess and till in south-central Iowa parallels in many respects the previous investigations made in southwestern, southern, and northeastern Iowa. The basic geologic and engineering properties of the sandy-silt immediately overlying the till and underlying the loess must be obtained first to understand and promote a satisfactory stabilization program. The field work on some of the phases of the petrography of till, loess, gumbotil and sandy-silt was conducted over an area of approximately 6,000 square miles in south-central Iowa, in Adair, Madison, Warren, Marion, Mahaska, Keokuk, Monroe, Wapello, Appanoose and Davis counties and part of Guthrie County (figure 1).

Except where indicated otherwise, the particle size classification is that of the American Society for Testing Materials (A.S.T.M. Designation: D422-54T[2]) and the American Association of State Highway Officials (A.A.S.H.O. Designation: M146-49[1]). These two classifications use the following size limits: sand 0.074 to 2 mm. diameter, silt 0.005 to 0.074 mm. diameter and clay less than 0.005 mm. diameter.

Glacial till mapped as Kansan outcrops in southern Iowa from the Missouri to the Mississippi rivers. Pre-Wisconsin till and loess occur together. Most of the calcareous till classifies as an A-6 engineering material, and till is important to the engineer where the loess is thin. Till outcrops over about 25 percent of the surface in the three lower tiers of counties across southern Iowa, except in Des Moines, Louisa, and Muscatine counties. Percentages of other geologic materials outcropping in the area are as follows: loess, 56 percent; alluvium, 18 percent; and bedrock, 1 percent[11].

Thickness of the till, or tills, in southern Iowa is not known accurately, but in most areas the till is at least tens of feet thick.

Stratigraphic Relationships.

Southern Iowa has two major drift sheets. The Nebraskan, the older, is overlain by the Kansan[7, 36]. A third, younger and less extensive drift sheet, the Illinoian, is in extreme southeastern Iowa. Without evidence of an unconformity or weathering profile between two drift sheets, the glacial till outcropping west of the area mapped as Illinoian in southern Iowa is assumed to be Kansan (figure 1).

No concentrated effort was made to find the contract of the two major tills, although some cited locations were visited in this research. Many of the exposures are now obliterated by slumping and erosion. However, in a drainageway in Grove Township, Adair County, Kansan till seems to overlie a Nebraskan gumbotil. The gumbotil grades down into a gleyed C

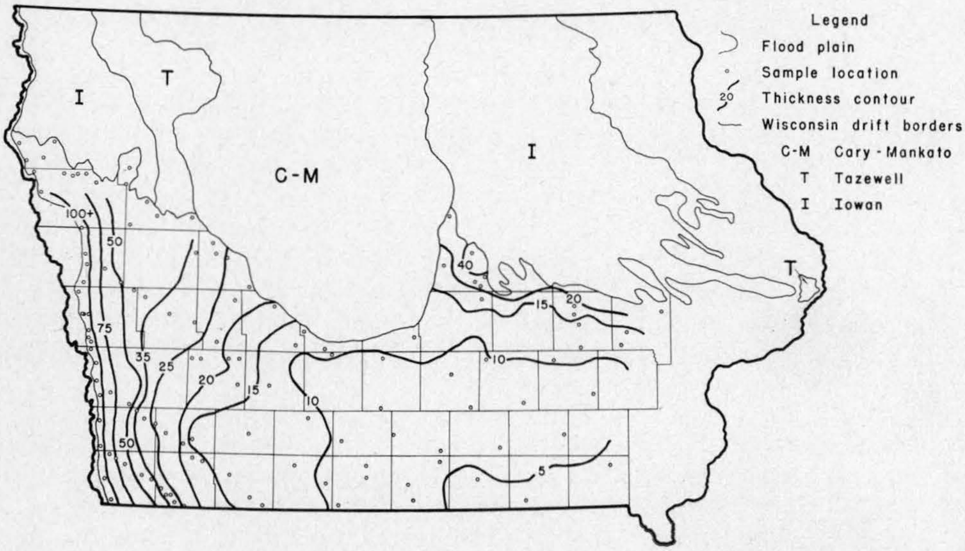
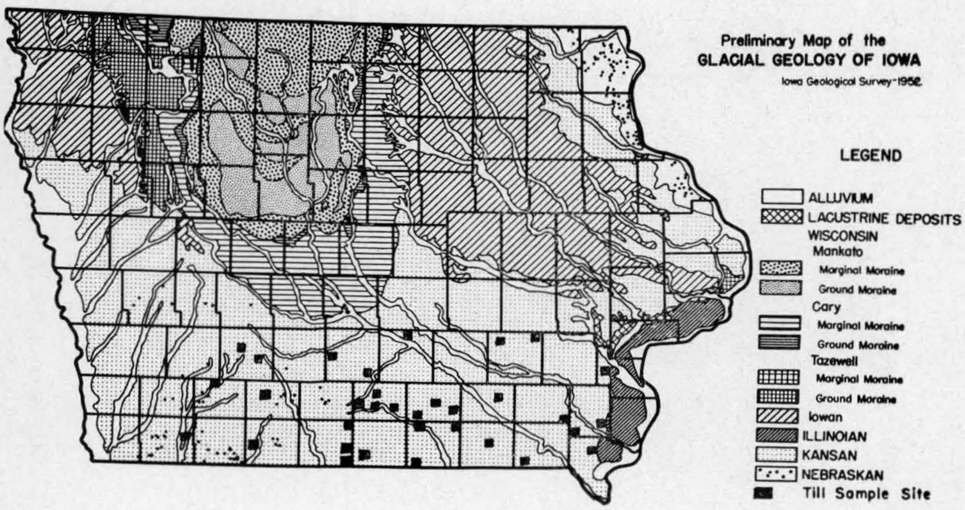


Fig. 1. above. Map showing locations of till sample cites.

Fig. 1. below. Map showing loess thickness in southern Iowa and locations of detailed samples.



horizon (looking much like the gumbotil) and this in turn grades into a brown calcareous till. Calcium carbonate concretions are near the top of the gumbotil.

Within the top of the Kansan till is sometimes a clay rich zone commonly known as gumbotil. In other profiles, the clay content of the upper part of the buried till is greater than that deeper within the till but probably not great enough to be considered a gumbotil.

In all road cuts and auger hole sections observed below the level of the higher, relatively flat interfluvial divides, a sandy-silt is above the till or the gumbotil. The sandy material grades up into the overlying clayey silt, called loess (figure 2). In auger holes drilled into the higher interfluves the amount of sand present in this lower zone is much less than that observed in the more rolling terrain, but here it also grades up into the overlying loess.

Glacial till. Most natural outcrops of Kansan till on the modern surface in southern Iowa are along the flanks of loess-capped hills in the more rolling terrain below the upland divides. Till exposures thus appear to be primarily a function of post-loess erosion, although post-loess creep and original loess thickness must also be considered.

The silt is thickest in the southwestern part of the state[11]; a higher per-

Fig. 2. Loess overlying Kansan till in Monroe County. The pick in center is at the contact of till and sandy-silt.

centage of the surface area in the central and eastern part of southern Iowa show till outcrops.

The till mass is predominately blocky aggregates of sand, silt, and clay. It is typically a clay, or clay loam (BPR textural classification[40]). The color of the calcareous and non-calcareous oxidized till can best be described as a yellowish-brown.

In general, the upper part of the till is non-calcareous, but it becomes calcareous with increasing depth. In some exposures, calcium carbonate concretions one inch or less in size are either within or at the top of the calcareous till. Sand lenses and pockets are quite common within the main body of the till. These deposits are usually non-calcareous and fairly well sorted, although the till mass is usually calcareous and always poorly sorted.

Where a deep roadcut or similar excavation has been made in the till, cracks assuming a crude polygonal pattern are observed. The segments outlined are typically from one to three feet in two-dimensional view. Ferric iron concretions are commonly concentrated along these joints and tend to outline blocks of till with a reddish-brown band about two inches wide. Occasionally calcium carbonate concretions are also present in the bands. The initial cracks are probably caused by mass movement, and the till outlined by bands occurs in three-dimensional blocks[28].

Gumbotil. Gumbotil is at the top of the till in southern Iowa. Its present distribution appears to be a function of erosion; it is persistently on the uplands, but not on the lower, more steeply rolling terrain. Because the sandy, clayey silt overlies relatively fresh till as well as more weathered till and gumbotil[11], pre-sandy silt and loess erosion must have determined the outcrop pattern before these younger sediments were formed or deposited.

The gumbotil discussed herein is restricted primarily to buried deposits rather than those which outcrop infrequently on the modern landscape in southern Iowa.

Gumbotil is mainly an aggregate mass of clay-size material with lesser amounts of silt, sand, and gravel. It is typically blocky peds with waxy coatings sometimes called "clay skins." When exposed in a roadcut, the clay-rich interval is easily recognized because of shrinkage cracks caused by drying. The highest clay content is near the top of the till, and the amount of clay decreases with depth (figure 2). The color is usually either a dark gray or reddish-brown, but there are variations in between. The gumbotil is non-calcareous, but grades down into calcareous till. When wet, it is plastic and tenacious; when dry, it is hard and blocky.

Pleistocene Geology.

Although much has been published on the Pleistocene geology of southern Iowa, most of the earlier work is on the Pleistocene geology in general, and information on the texture and mineralogy of the unconsolidated sediment is devoted primarily to the coarser size fractions. The largest single compilation of data on the Pleistocene geology of southern Iowa, with a bibliography of the Pleistocene of Iowa, was written in 1944[24].

Geologic reports for many counties in south-central Iowa were prepared by members of the Iowa Geological Survey from 1896 to 1916.

Loess. Information on loess is quite voluminous. All of the county geologic reports mention loess in south-central Iowa, but there is little or no information on its thickness, mineralogy, or texture. A bibliography of the loess has been published[12].

Sandy-silt. Sandy-silt refers to material which overlies the till and underlies the loess in many places in south-central Iowa. As far as could be determined little or no work has been done on this material in Iowa other than that done recently[32]. However, in the lower valley of the Mississippi River gravel and sand is mixed with the silt in the basal portion[35].

In Adair County, Iowa, the slopes along the axes of interfluves are a sequence of stepped levels that rise from the valley shoulders of the modern valleys to the upland divides[22]. This sequence of levels is probably due to the multicyclic erosion of a glacial till landscape, and these surfaces can be dated by the intensity of weathering they have undergone and by the presence or absence of a loess cover.

The highest surface is the Yarmouth-Sangamon, a weathered relic of the Kansan drift plain which though highly weathered has not been changed by erosion since Kansan time. It is mantled by Farmdale-Iowan-Tazewell loess.

The intermediate surface is the Late Sangamon erosion surface (called a pediment) which is capped by a lag-gravel erosion pavement (stone-lime), finer-textured sediment (pedi-sediment) derived from till and in most places by Farmdale-Iowan-Tazewell loess. A buried soil (below the loess and less well-developed than the Yarmouth-Sangamon paleosol) developed in the pedi-sediment, stone-lime and upper part of the Kansan till.

The lowest surface level of the landscape is the Early Wisconsin pediment that is cut into Kansan till below the Late Sangamon surface. Since no paleosol is observed separating the till from the loess, it is postulated that loess deposition closely followed the cutting of this surface. However, in some places where the loess cover has been stripped from this surface a soil developed in Kansan till is observed.

Weathering ratios, clay content of the B horizon, and thickness of the B horizon used to correlate these geomorphic surfaces with the nature of soils developed on them.

South-central Iowa loess, for the most part, was deposited during the Iowan and Tazewell substages of the Wisconsin glacial stage. Loess deposited during this time corresponds to the lower part of the Peorian, which corresponds to the lower Wisconsin unit[29]. Loess older than Iowan was not observed or could not be recognized as such in the eastern area of study (in which area most of the loess sampling was done). However, in Adair County, a thin interval of loess has been identified as Farmdale[32].

Field Characteristics.

Glacial till. On the modern surface in south-central Iowa most natural outcrops of glacial till occur along the flanks of loess-capped hills in the more rolling terrain below the upland divides. Till exposures thus appear to be primarily a function of post-loess erosion; although it is recognized that post-loess creep and original loess thickness must also be considered.

Some of the profiles now exposed on the modern landscape may be the result of weathering and profile development that began in Yarmouth time, subdued after loess deposition ,and now active again. If the unconsolidated material and its soil profiles now observed in south-central Iowa are likened to superimposed layers of sedimentary rock, in some places the material that now occurs on the modern landscape may have at one time been exposed on a paleo-landscape, buried and re-exposed by subsequent erosion. This is shown in almost any roadcut deep enough to expose the loess-till contact on the flank of a hill, especially if there is a well-developed weathering profile in the till (figure 2)[32].

Since the loess generally decreases in thickness from northwest to southeast, till soils occur over a higher percentage of surface area in the south-

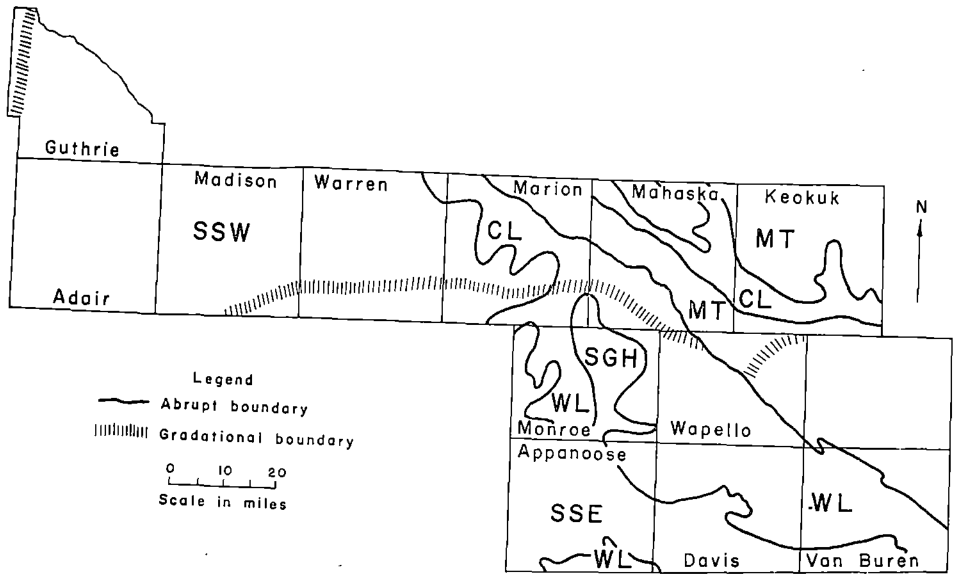


Fig. 3. Principal soil associations within the area of study. SSW: Shelby, Sharpsburg and Winterset; CL: Clinton and Lindley; WL: Weller and Lindley; SGH: Shelby, Grundy and Haig; MT: Mahaska and Taintor[39].

eastern part of the region (figure 3). The till is composed predominantly of blocky peds and is typically a clay loam[43]. The color of the calcareous and non-calcareous till can best be described as a yellowish-brown (mostly 10YR6/3 to 10YR6/4).

In general the till (encompassing the A, B, and part of the C horizons) is non-calcareous but becomes calcareous with increasing depth. In all profiles the A and B horizons are non-calcareous. In some exposures calcium carbonate concretions are present within or at the top of the calcareous till. They typically have maximum dimensions of one inch or less.

Sand lenses and pockets are quite common within the main body of the till (figures 4, 5). These deposits are usually non-calcareous and fairly well sorted, although the adjacent till mass is usually calcareous and always poorly sorted.

Where a deep roadcut or similar excavation has been made into the till, cracks assuming a crude polygonal pattern are observed. The segments outlined are typically from 1 to 3 feet in two-dimensional view. Ferric iron concretions are concentrated along these cracks and tend to outline blocks of till with a reddish-brown band about 2 inches wide. Sometimes calcium carbonate concretions are also present in the bands. These initial cracks are probably caused by mass movement and the till outlined by bands occurs in three-dimensional blocks[28].

Exposed in a new roadcut along Highway 25 in NW¼ of SW¼ of SW¼, section 20, Jefferson Township, Adair County, is an example of these iron bands surrounding blocks of till in both the oxidized yellowish-brown till and in the lower unoxidized blue till. Apparently the cracks in the till allow water to percolate more freely and to concentrate the iron in these

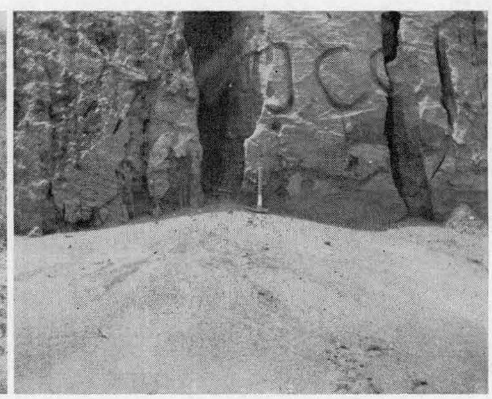


Fig. 4. at left. Sand lens in Kansan till in Adair County. Hoe and spade in lens give scale.

Fig. 5 at right. Sand pocket in Kansan till in Monroe County. Note extensive gullying in the sand and small alluvial fan extending out from base of gully.

bands. Obviously the ferric iron bands are either deposits of iron brought in from some outside source or are deposits of iron in some manner brought out of the blocks of till they surround, because if the bands were merely zones of oxidized iron in the same concentration as in the blocks of till, then these blocks of till should also assume the same reddish-brown color with time as oxidation within them becomes more complete. Since the till as a whole is homogenous and the iron bands occur in both the yellowish-brown and blue till, it seems more likley that most of the iron has moved out of the blocks of till while in the ferrous state and become concentrated along the outlining bands. This could explain the yellowish-brown color of the above till and suggest that the underlying blue till will sometime become yellowish-brown.

Gumbotil. Gumbotil, which is at the top of the till, appears to be a result of erosion; it is found persisently on the uplands but not on the lower, more steeply rolling terrain in south-eastern Iowa.

The gumbotil discussed is restricted mainly to the buried deposits rather than that which might outcrop over a reasonably large surface area on the modern landscape.

In many instances on the more rolling, dissected terrain, sandy-silt and loess overlie till which does not have a heavy clay zone in its upper part. Although this till may show some evidence of a weathering profile with depth, it is not mature enough to be considered a gumbotil. That is, field inspection may reveal a fairly high percentage of the more easily weathered minerals and a mechanical analysis may show only slightly more clay than that deeper within the till.

The gumbotil is a clay with lesser amounts of silt, sand, and gravel. It typically occurs as blocky peds with waxy coatings known as clay skins. The clay rich zone is easily recognized in roadcut exposures because of shrinkage cracks caused by drying. The zone of highest clay content is near the top of the till and the amount of clay decreases with depth. In roadcut exposures it is usually 2 to 4 feet thick. The color is usually either a dark gray or reddish-brown but there are variations between these. The reddish-brown gumbotil is sometimes called ferreto gumbotil. The gumbotil itself is non-calcareous but may grade into calcareous till. When wet it is plastic and tenacious, when dry it is hard and blocky.

When auger holes are drilled through the loess and into the gumbotil on the uplands, a water saturated zone is often just above the gumbotil. Since no holes were drilled completely through the heavy clay it is not known for sure whether this saturated zone was the true water table for a particular area or merely a perched water table on the heavy clay.

Another stratigraphic interval which is sometimes present between the till and the sandy-silt is a layer or zone of rocks called *stone-line.* Where exposed in a roadcut this stone-line is always overlaid by sandy-silt, but in as many exposures as not, sandy-silt has been exposed overlying a till or gumbotil without the presence of a well-developed stone-line. The stone-line is commonly two to four inches thick and is of gravel size material similar to that in the till (figures 6 and 7).

The stone-line may be a part of the process of landscape evolution in southern Iowa and may be a lag-gravel erosion pavement in the Late Sangamon erosion surface[32].

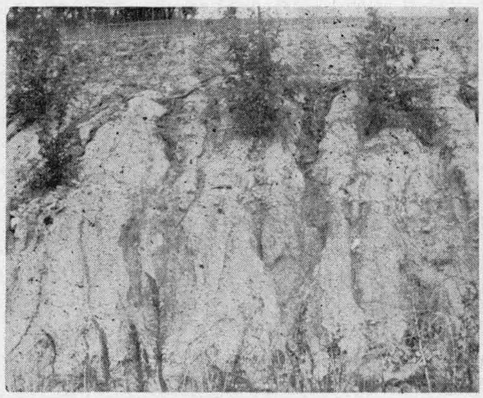
Loess. Loess is over most of the terrain in south-central Iowa, the major exceptions being the drainage-ways and the lower slopes adjacent to stream valleys. It generally decreases in thickness across the state from west to east, but in a smaller area or watershed within south-central Iowa its thickness may decrease in any direction from the top of a hill in dissected topography (figure 1). It appears as though erosion, possbily operating under a number of processes, predominately determines the present outcrop pattern of the loess. This is evidenced by the decrease of loess thickness downslope toward drainage-ways until, in some cases, other sediment is exposed.

The loess is predominately silt with a lesser amount of clay and very little sand. It is typically a silt loam or silty clay loam.

The G horizon usually varies from a yellowish-brown (10YR5/6) to grayish-brown (2.5Y5/2) in color. It is usually mottled lightly with varying shades of gray, and occasionally the lower part of the loess is gray.

In the area studied the loess is non-calcareous, and always with iron concretions of sand size and smaller and small black concretions of manganese oxide.

In fresh roadcuts the loess is an homogenous unstratified body and main-



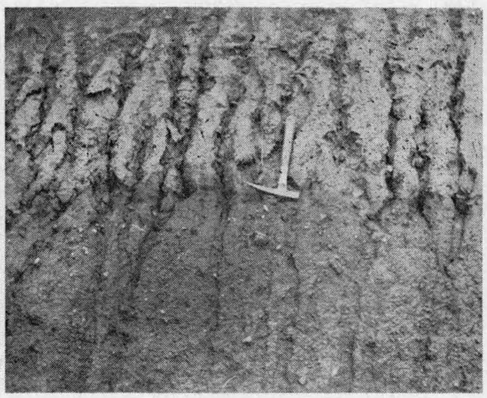


Fig. 6 at left. Stone-line developed in Kansan till in Monroe County. Pick is at the contact of stone-line and sandy-silt.

Fig. 7 at right. Loess overlying Kansan till in Mahaska County. Note absence of well developed stone-line. Pick is at the contact of till and loess.

tains steep faces. Its porosity is evidenced by the manner in which it soaks up dilute hydrochloric acid when tested for calcareousness.

In south-central Iowa well developed vertical jointing in the loess is rather rare compared with that of western and southwestern Iowa. No catsteps are visible on the hill slopes. It seems feasible that the thinness and finer particle size of the loess may be responsible for the apparent absence of these shear planes or, if formed, the high moisture content may tend to "heal" them.

No multiple loesses of different ages were found within the area of dominant study. No buried soil profile was recognized in borings in the loess or in roadcuts deep enough to reveal considerable loess thickness. The only exception was in Adair County where loess identified as Farmdale was noted in auger holes bored into the upland[32].

Sandy-silt. In all roadcuts which expose the contact of the till and loess, an intermediate interval, called here the *sandy-silt*, is present. In auger holes bored into the upland divides there is a sandier zone below the loess, but its particle size with depth has different characteristics and its sand content is lower per foot of depth than that exposed in roadcuts.

Relative relief is a factor to be considered in occurrence of the sandy-silt as well as other horizons already discussed.

The sandy-silt is typically a loam or silt loam which is called sandy-silt because silt is usually the single dominant particle size and because the amount of sand within it is in striking contrast with the extremely low amount in the overlying loess.

When examined in a roadcut usually the only way to detect sandy-silt is by scraping down the cut with a hoe or spade. A definite grittiness is noticed when the hoe enters the more sandy interval. When one is augering, its presence can usually be detected by the sound of the bit moving into the sandy material. Megascopic examination will then reveal sand grains. In the field no definite contact may be determined, but the transition zone is rarely more than five inches.

Occasionally the whole interval exhibits a slightly lighter color (a light yellowish-brown or gray—10YR5/3 or 10YR6/2) than either the overlying loess or underlying till, and its position can be roughly outlined for the length of a roadcut.

Its thickness in roadcuts varies from one to three feet, and in all exposures observed it is non-calcareous. It is essentially unconsolidated and shows no visible bedding.

Specimens of material taken from below the main body of the loess on upland flats by means of augering show a particle size distribution with depth similar in many respects to that present on the more hilly terrain.

SELECTION OF SAMPLES

In selecting sample sites (table I, figure 1), one of the principal objectives was to determine both the local and regional variation in the till. An attempt was made to unbias the operator in selecting sample sites so that a truly random selection of samples could be made. The nature of typical and representative glacial till was needed, not only for the present study, but also for a check on observations made by previous workers; yet this selection was made by workers without previous training and experience in Pleistocene geology.

In cooperation with the statistics department of Iowa State University such a system was devised[28]. Within the area of study, the total outcrop area of soils developing from glacial till was computed by using published soil maps. The area was then divided into equal parts, based on area of outcrop of glacial till. Regions where outcroppings of glacial till were highest were thus given proper consideration.

The available funds limited the number of samples which could be taken. The areas of equal glacial till outcrop were subdivided and numbered. These numbered supersections could then be picked by the use of a table of random numbers.

This method for all the sampling of Kansan till has proved to be both efficient and relatively rapid after the original conditions were set up.

Field Methods of Sampling. When a sample site had been selected (all major sample sites were road cuts) the following information was recorded:

1. A complete profile including color, texture, structure, thickness.
2. Surrounding topography.
3. Accessibility for further field tests and sampling.
4. Soil series.

TABLE I. SAMPLE SITES

Sample site	Section	Tier and Range	Township	County	Soil series	Parent material
413	NW¼NW¼ sec. 20	T72NR17W	Monroe	Monroe	Lindley	Till
414	NE¼NE¼ sec. 34	T72NR16W	Mantua	Monroe	Shelby	Till
415	NW¼NW¼ sec. 14	T67NR19W	Franklin	Appanoose	Shelby	Till
416	SW¼SW¼ sec. 6	T76NR25W	Jefferson	Warren	Shelby	Till
417	SE¼NE¼ sec. 31	T76NR32W	Prussia	Adair	Shelby	Till
418	SW¼SW¼ sec. 24	T76NR31W	Grove	Adair	Shelby	Till
419	NW¼NW¼ sec. 12	T70NR19W	Independence	Appanoose	Shelby	Till
420	NW¼NW¼ sec. 33	T75NR22W	White Breast	Warren	Shelby	Till
421	NW¼SE¼ sec. 32	T71NR18W	Franklin	Monroe	Shelby	Till
422	NW¼SW¼ sec. 13	T77NR20W	Red Rock	Marion	Lindley	Till
423	NW¼NW¼ sec. 21	T70NR16W	Union	Appanoose	Lindley	Till
523	NW¼NW¼ sec. 32	T75NR14W	White Oak	Mahaska	Clinton	Till
524	SW¼SW¼ sec. 29	T77NR17W	Richland	Mahaska	Clinton	Loess
525	NE¼SW¼ sec. 34	T72NR16W	Montus	Monroe	Grundy	Loess
526	NW¼NW¼ sec. 2	T68NR18W	Center	Appanoose	Grundy	Loess
527	NE¼NE¼ sec. 3	T77NR13W	Prairie	Keokuk	Otley?	Loess
528	NW¼NW¼ sec. 7	T75NR10W	Clear Creek	Keokuk	Mahaska?	Loess
530	NW¼NE¼ sec. 5	T69NR13W	Perry	Davis	Weller?	Loess
531	NE¼SE¼ sec. 8	T70NR9W	Union	Van Buren	Grundy	Loess

At least one 20 pound sample or more was taken from each of the A, B and C horizons to be used for testing in the laboratory.

Samples for Detailed Study. On the basis of field description, mechanical analysis, and Atterberg limits, a sample of both a C horizon till and loess were chosen for petrographic study. These chosen samples, along with others from the same site, were also subjected to various other physical and chemical tests. A gumbotil and a sandy-silt sample were also chosen for analysis under the petrographic microscope.

Site No. 416 in Warren County, the detailed till section, is located on a spur slightly below the level of the upland in a rolling terrain, where slopes of 8 to 10 degrees are common (figure 8). The detailed loess, sandy-silt, and gumbotil section, No. 528, is located in Keokuk County in undulating to rolling terrain with slopes of 3 to 6 degree (figure 9). This sample site lies in a transition zone between the Clinton-Lindley and Mahaska-Taintor soil association areas (figure 2). It is on a spur of upland which extends out to the east toward a small valley and which slopes off gently to the north and south to intermittent drainage-ways.

LABORATORY PROCEDURES

Mechanical Analysis.

Mechanical analyses were performed on all samples to determine the size frequency distribution of the constituent particles by the hydrometer and sieving method (A.S.T.M. Designation: D422-54T) as modified[9] (figure 10). Sodium metaphosphate was used as the dispersing agent. The fraction re-

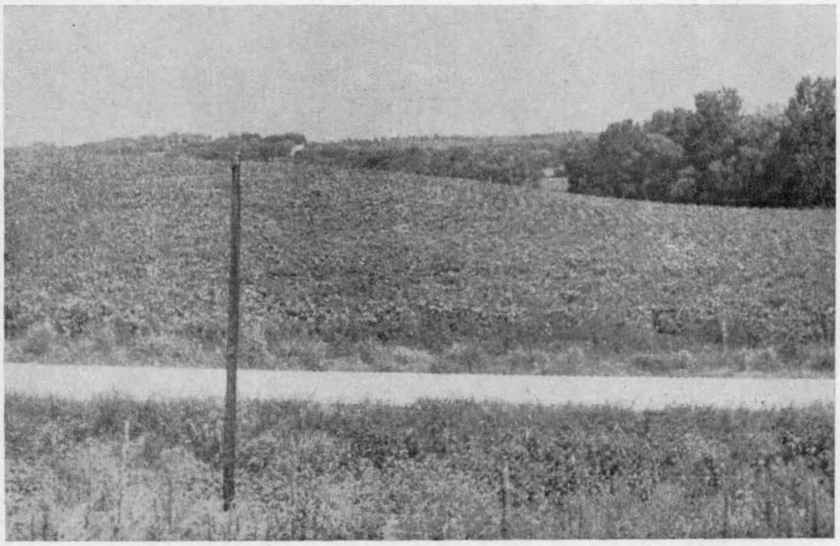


Fig. 8. View of rolling topography in area of sample site No. 416. Warren County.

tained on the No. 200 sieve was then dry sieved through the following nest of sieves: Nos. 20, 40, 60, 100 or Nos. 140 and 200.

Physical Tests.

The only physical tests were those necessary to determine the engineering classification of the soil. These soil-water consistency and classification procedures include:

Liquid limit: (A.S.T.M. Designation: D423-54T)[2];

Plastic limit: (A.S.T.M. Designation: D424-54T)[2];

Plasticity index: A.A.S.T.M. Designation: D424-54T);

Engineering classification: Bureau of Public Roads[40].

The Atterberg limits were determined by laboratory personnel. A number of standard engineering tests, of particular interest to the stabilization program, are available at the Iowa Engineering Experiment Station Soils Research Laboratory.

Chemical Tests.

Chemical tests bearing primarily on engineering usage were performed by laboratory personnel. These tests and methods include:

1. Calcium carbonate: leaching and titration with versenate solution;
2. pH: Leeds and Northrup Co. pH meter;
3. Organic matter: by a dichromate oxidation method[10];
4. Cation exchange capacity: by an ammonium acetate method[14].

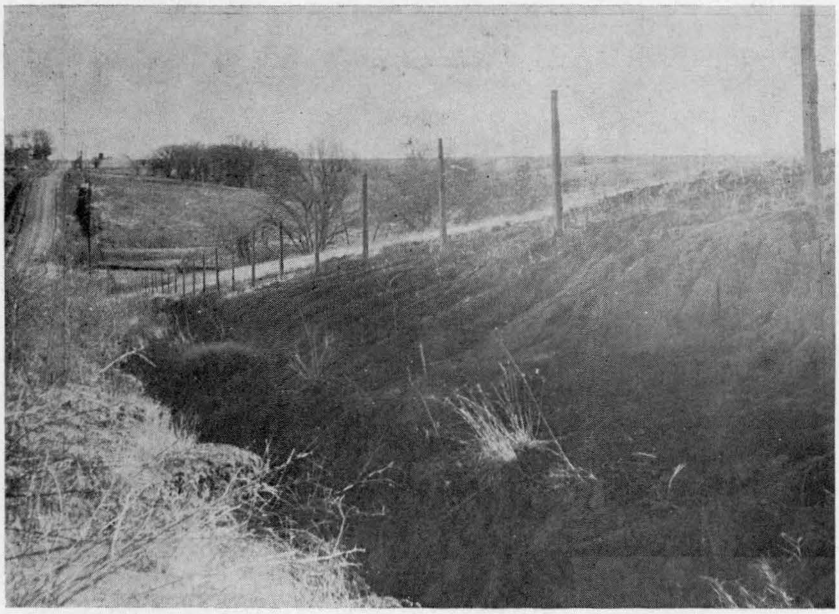


Fig. 9. Topography in area of sample site No. 528, Keokuk County. Lower pick in center of photograph lies on ferreto gumbotil, upper pick on sandy silt.

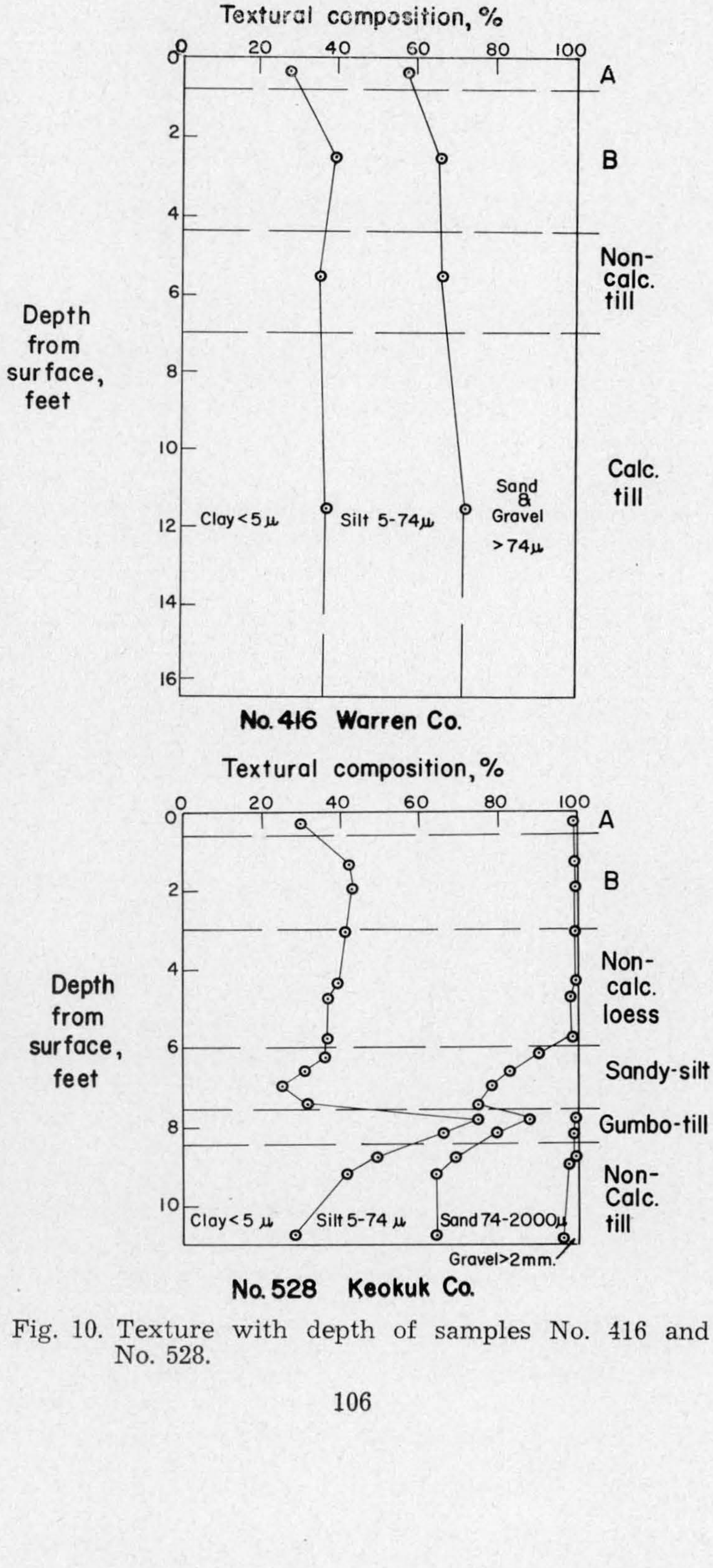


Fig. 10. Texture with depth of samples No. 416 and No. 528.

Mineral Determinations.

Fifty grams of each of the four materials to be studied with the petrographic microscope and by X-ray diffraction were separated by dispersion, elutriation, sieving, and pipetting. Dispersion was by the same method used for mechanical analysis, and elutriation was performed in a rising-current elutriator[20].

The size fractions to be studied with the petrographic microscope were permanently mounted in Lakeside cement (index to refraction similar to balsam, 1.534 to 1.540).

Mineral identification was made with a Leitz petrographic microscope by identifying grains along traverses. At least 250 and usually 300 or more grains were counted in each particular size fraction.

Clay Mineral Studies.

Differential thermal analysis. All till A, B and C horizons (using material finer than 44 microns) were analyzed with a differential thermal analysis apparatus[20, 25]. A few loess samples were also analyzed. All samples were kept in an atmosphere of 50 to 55 percent relative humidity for at least two weeks prior to analysis.

X-ray analysis. A General Electric diffractometer (Model XRD-5) was used to study several size fractions of the selected loess, till, sandy-silt, and gumbotil samples. Copper K alpha radiation and a nickel filter were used, and the samples were scanned at a rate of 2° per minute using a 0.2° detector slit. All samples were treated with ethylene glycol for at least one run, and all were packed in a bakelite sample holder. Some samples greater than 74 microns were analyzed, and these were ground prior to X-raying.

DATA

Particle-Size Analysis.

Glacial till. The widest range of particle-size distribution for all A, B, noncalcareous and calcareous till horizons is shown by the B horizon (figure 11). This might well be expected, since all samples were plotted regardless of topographic position, soil series, or maturity of development. Considering the wide geographic spread of the sample area, the textural range of the calcareous till, or that material which could be considered most nearly the parent material (least weathered), is fairly uniform. It has the least textural spread of any of the four horizons.

There is no regional trend in the distribution of texture. The samples that show the maximum difference in texture are located in adjacent counties (No. 413 in Monroe County and No. 419 in Appanoose County). The major difference in texture between the various horizons involves the clay-size material. That is, the A horizon consistently shows less clay and the B horizon more clay than the calcareous till.

All of the till is poorly sorted because the relatively high clay content

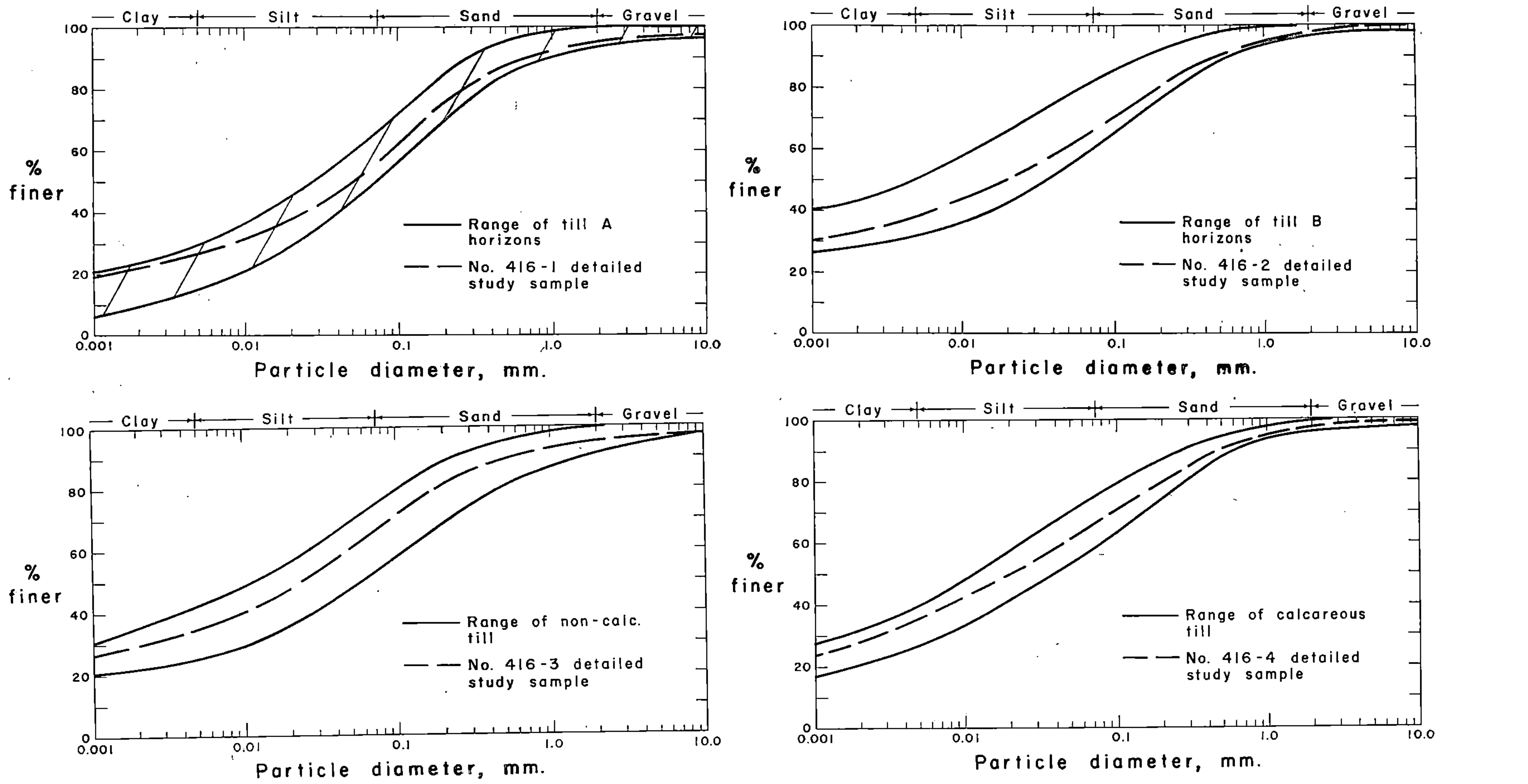


Fig. 11. Range of particle-size distribution for all A, B, non-calcareous and calcareous till horizons.

gives a very small diameter for the smaller quartile[42]. However, the sand pockets in Nos. 414 and 419 (figure 12) and the silt pocket in No. 423 (figure 13) have values of S_0 equal to 1.9, 2.3 and 1.9 respectively. Well-sorted marine sediments have values of S_0 less than 2.5; moderately sorted sediments range from 2.5 to 4.0; and poorly sorted sediments have values greater than 4.0[42].

The median diameter of sample No. 416-4 is 0.020 mm. and for all till horizons the diameter ranges from 0.005 to 0.072 mm. (figure 14). The range

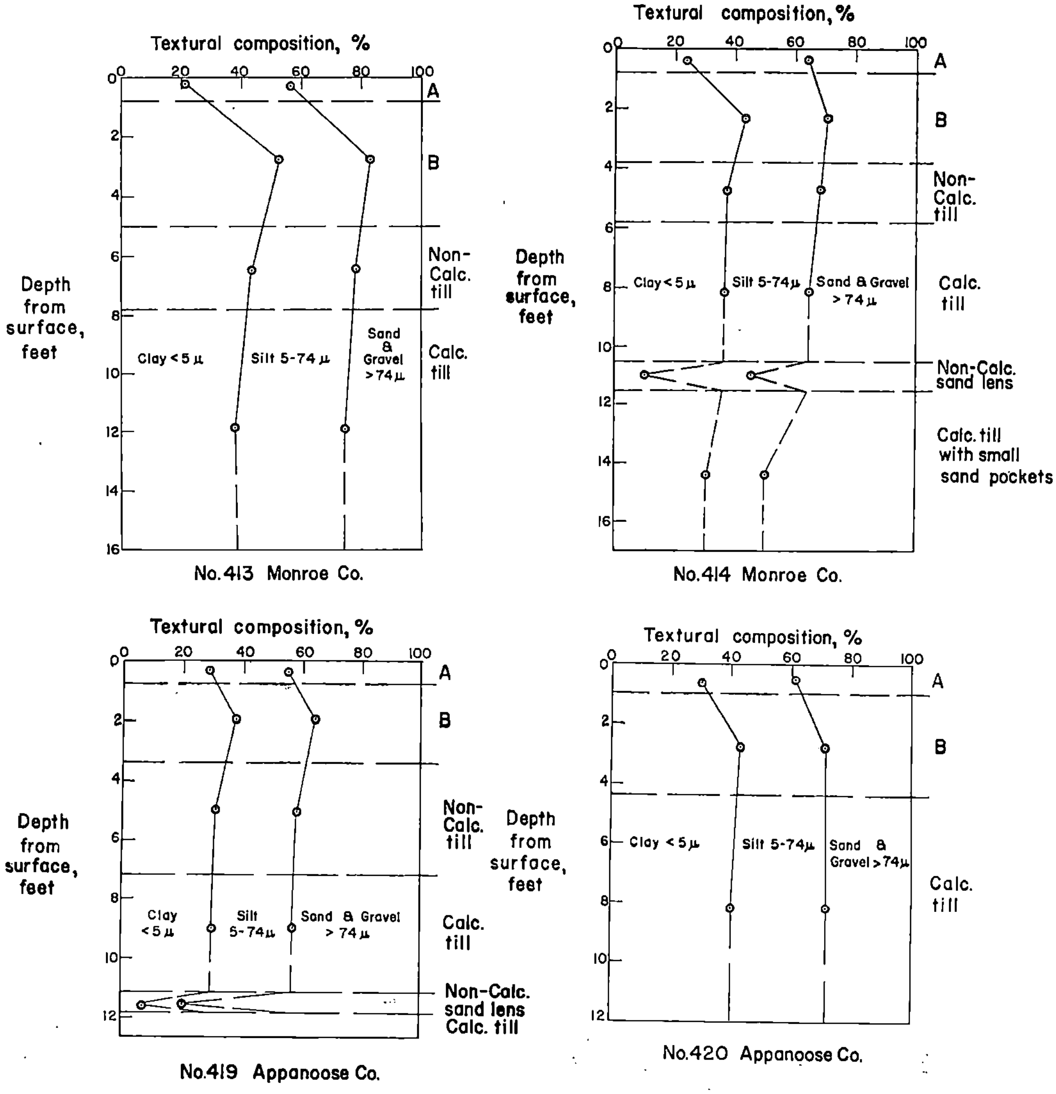
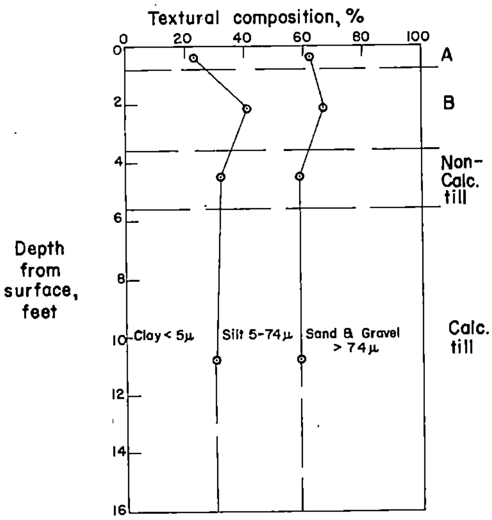
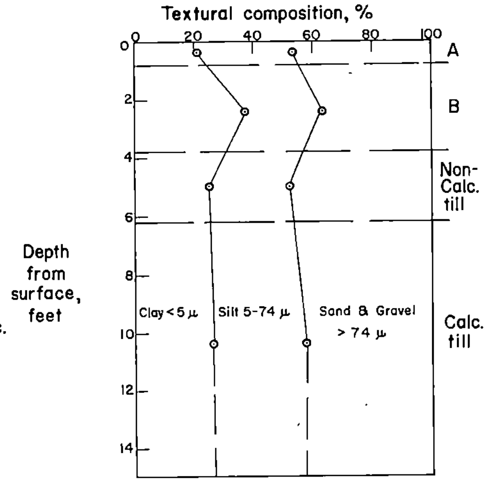


Fig. 12. Texture with depth of several till profiles.

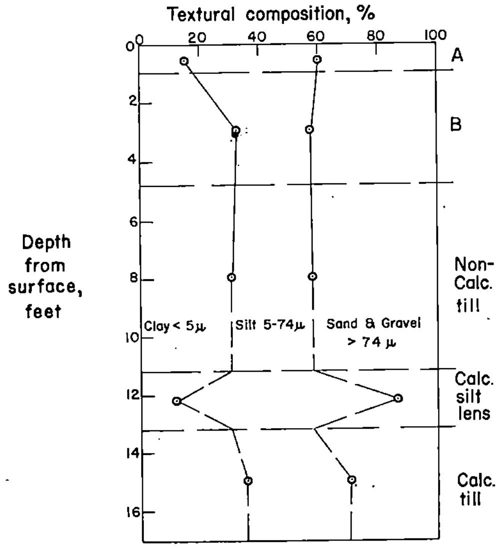
of median diameters for the separate till horizons is as follows: A, 0.027 to 0.072 mm; B, 0.005 to 0.036 mm; non-calcareous till, 0.011 to 0.062 mm; and calcareous till, 0.011 to 0.038 mm. Less clay is in the A horizons (higher median diameter), more clay is in the B horizons (lower median diameter), and the calcareous till has the least spread of textural variation. The median diameter, which represents the middle grain (associated with the second quartile or 50 percent line) with an equal weight-frequency of grains on both sides, is the average grain diameter of the sediment. But this figure



No.421 Monroe Co.



No.422 Marion Co.



No.423 Appanoose Co.

Fig. 13. Texture with depth of several till profiles.

for median diameter is not as meaningful in such a poorly sorted sediment as glacial till as it is in a well-sorted sediment (figure 14). The median diameter of a glacial till (poorly sorted) does not fall in that size fraction which contains the highest weight-percentage frequency of material, while the median diameter for the sand (well-sorted) does fall into the size fraction containing the most material.

The most prominent feature of the graphs showing textural composition is that the vertical variation in particle-size distribution is actually quite slight considering the general nature of glacial till (figures 12, 13). The only major variations are the increase in coarser fractions in the A horizon, increase of clay in the B horizon, and that caused by local sand or silt pockets. In general, below about four feet the main body of the till, excluding lenses and pockets of sand or silt, shows little textural variation. In most profiles the difference in clay content between the B and C horizons is less than the difference between the A and B horizons. The depth to calcareous till is usually about six feet. The main body of the Kansan till within the area of study with some variations can be roughly broken into

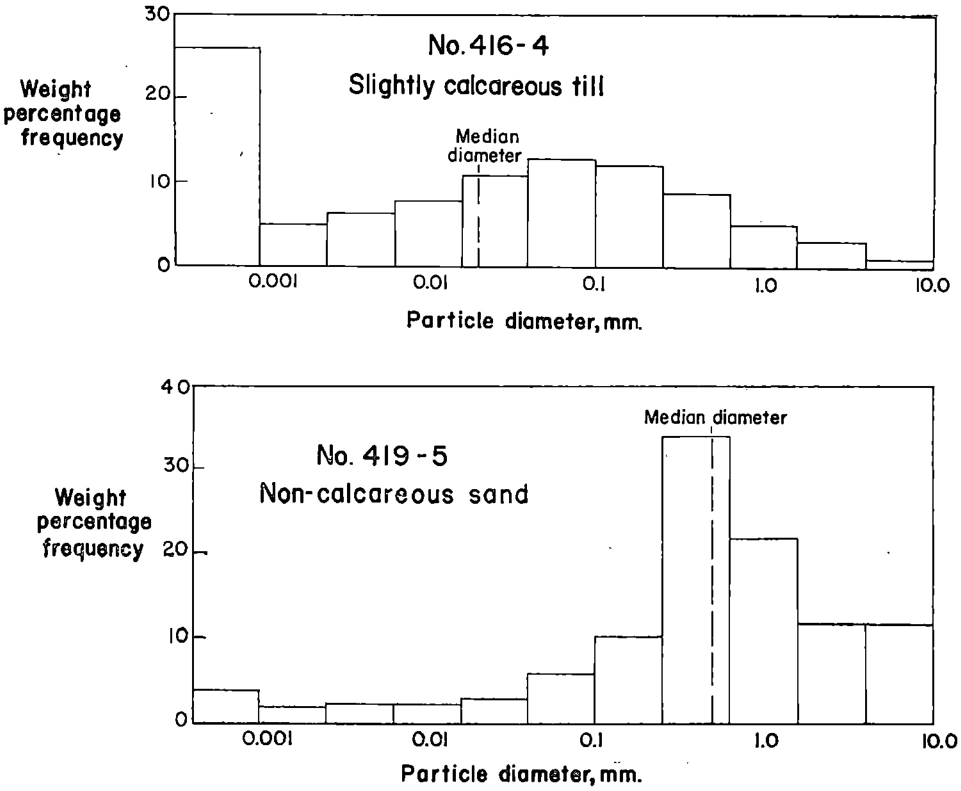


Fig. 14. Histograms with median diameters of samples No. 416-4 and No. 419-5.

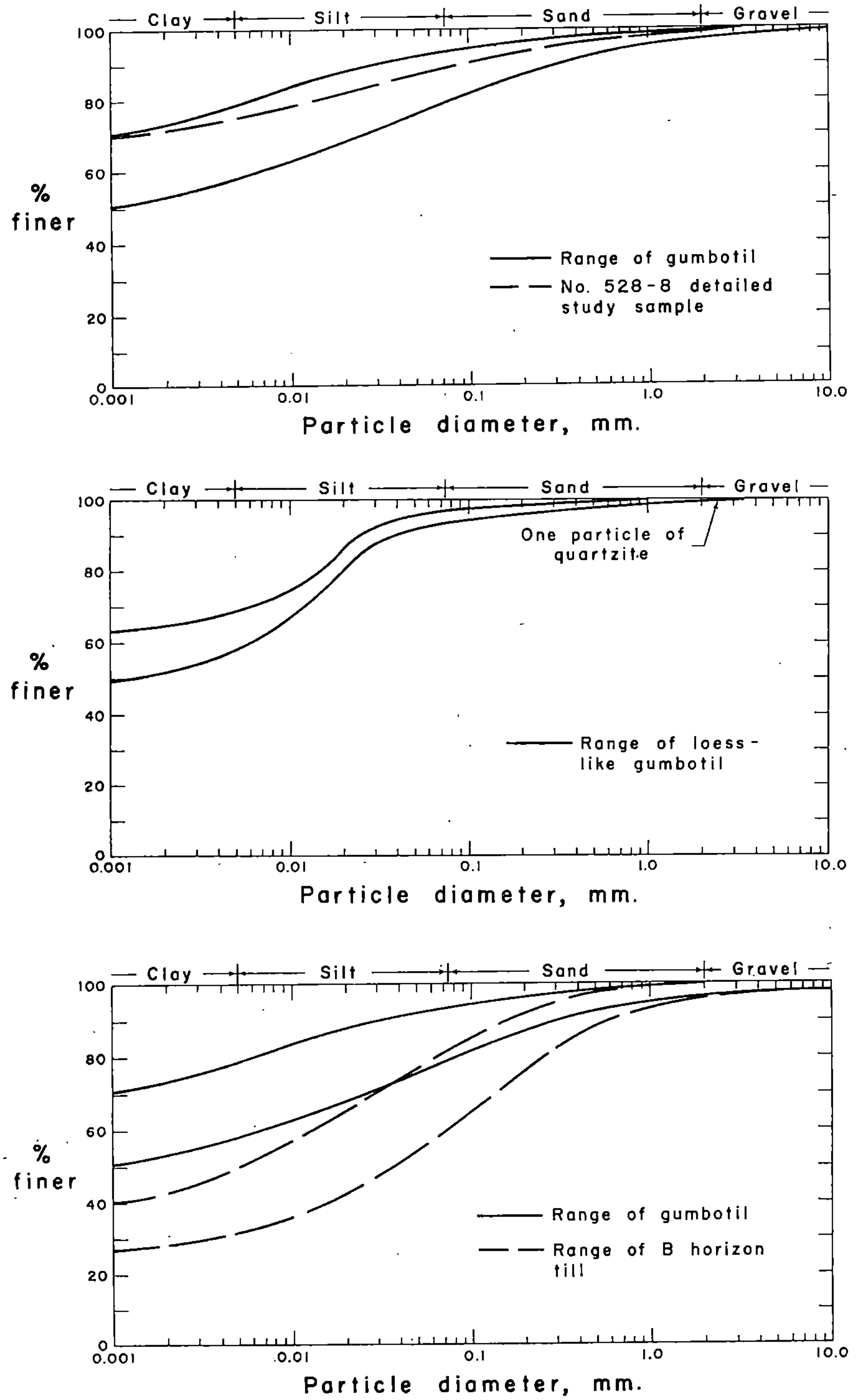


Fig. 15. Range of particle-size distribution for heavy clay materials in south-central Iowa.

thirds, one each of clay, silt, and sand and gravel. The gravel fraction is ordinarily below 4 percent.

Gumbotil. Eight samples of gumbotil were taken either from roadcuts or auger holes, and all sites are in rolling terrain or on spurs of upland extending out into more rolling topography (figure 1). These samples were all immediately overlain by sandy-silt and were in the eastern part of the area of study.

True gumbotils are thought to be extremely weathered till and so should show the same general type of cumulative curve as a till except for a higher percentage of the fine material. These samples appear to show this relationship (figure 15).

Six samples considered to be gumbotil were also taken from auger holes on apparent topographic highs or well within the limits of uplands with a relatively flat or gently undulating topography. The cumulative curves for these samples resemble a loess curve with a high clay content and would probably be classified as loess-like gumbotil[28], but there is a significant change in mineralogy of the coarse fractions of these samples.

Loess. As in the till, the widest spread of textural variation in the loess is shown by the B horizon (figure 16). The non-calcareous loess, that material lying above the sandy-silt and below the B horizon has the slightest range of variation in texture. A slight regional trend shows in the particle-size distribution of this material. The sand content remains constant, but there is a slight increase in clay and a corresponding decrease in silt to the south and east. Samples taken from Davis and Appanoose counties show the highest clay content in the non-calcareous loess. The loess thickness follows this same general trend; the loess thins in general to the south and slightly to the southeast within the area of study.

All of the loess is poorly sorted except for an occasional A horizon[42]. This is because in most instances the clay content is high enough to give a small diameter for the smaller quartile. But in a few A horizons enough clay has been removed to give a larger diameter for the smaller quartile, and this material then falls into the moderately sorted range. All the loess is better sorted than any of the till (excepting silt and sand pockets in the till), but both the loess and till are poorly sorted. In several of the loess sample sites the total texture varied with depth (figure 17). The sand content of the loess is very low, clay decreases in the A horizon and increases in the B horizon, and the loess is uniform in texture from the sandy-silt up to the base of the solum. The loess of south central Iowa in general contains roughly one-third clay and two-thirds silt.

Median diameters for the different loess intervals vary: A, 0.0094 to 0.017 mm; B, 0.0046 to 0.012 mm; and non-calcareous loess, 0.0092 to 0.014 mm. The A horizon loess consistently contains less clay (higher median dia-

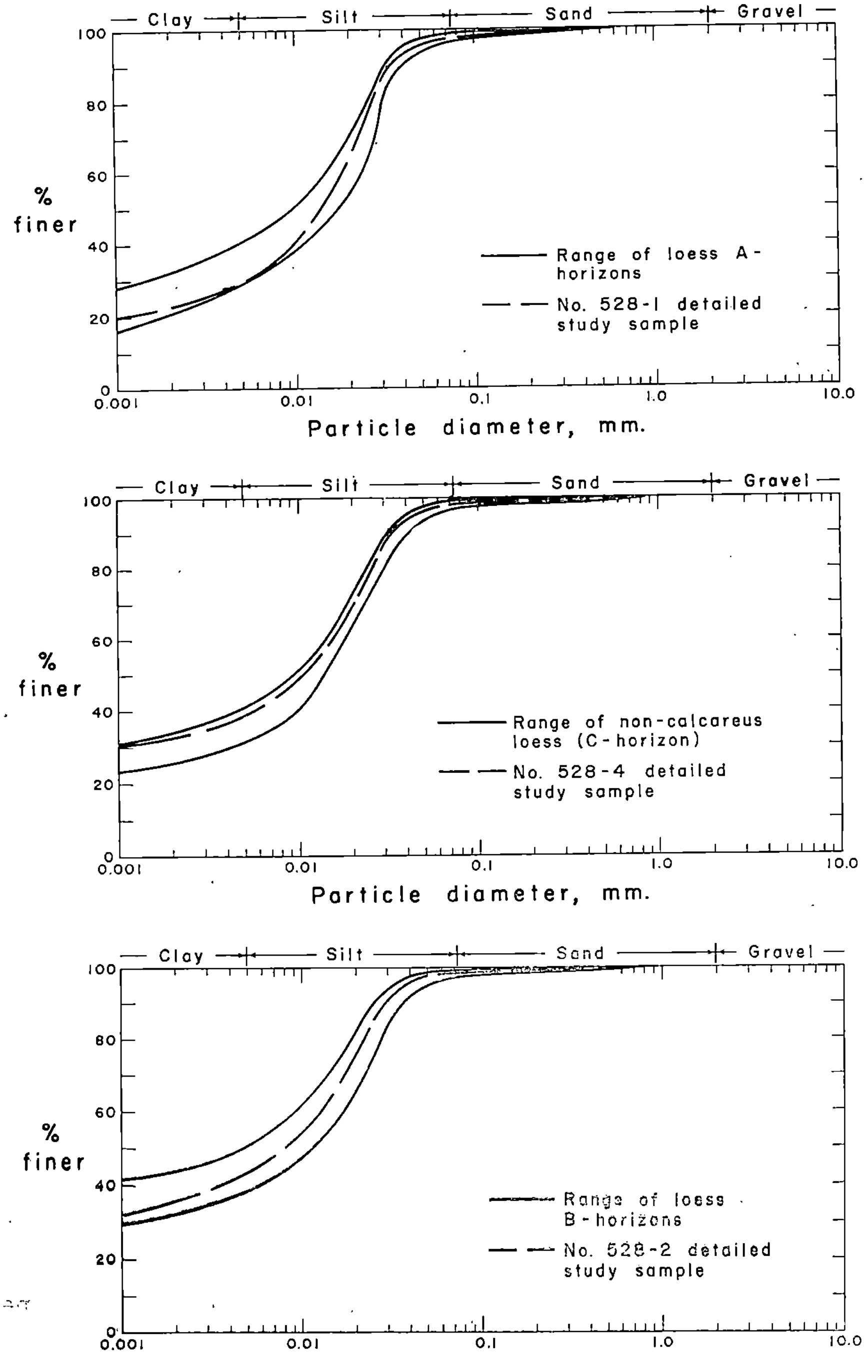


Fig. 16. Range of particle-size distribution for A, B, and non-calcareous loess horizons.

meters), the B horizon more clay (lower median diameter) and the non-calcareous loess has the least spread of textural variation.

Sandy-silt. Since topography appears to be related to the amount of sand in the sandy silt and to some extent with its thickness, these data on the particle-size will be presented under two general headings: rolling topography and upland topography.

Rolling topography designates that landscape which occurs below the level of the relatively flat upland divides and extends down to the present floodplains.

In many cumulative curves of the sandy-silt in rolling topography a very irregular type of curve tends to be bimodal or even trimodal in character. Many of these profiles were sampled before interest was shown in the

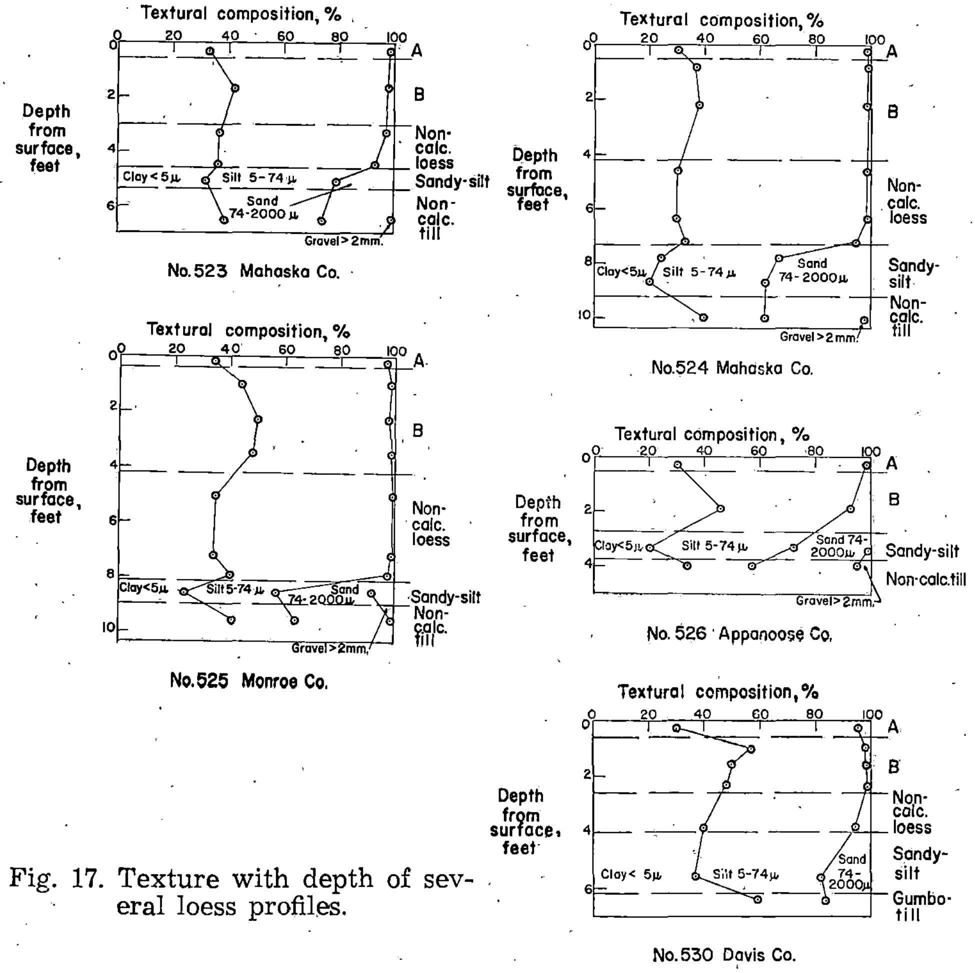


Fig. 17. Texture with depth of several loess profiles.

sandy-silt, hence they show only one or two samples from within this interval (figures 10 to 18).

In relation to the overlying loess, the sandy-silt always contains more sand and less clay (figures 10, 17, 18). In all profiles the sandy-silt contains less clay than the underlying till or gumbotil. If underlain by a gumbotil or fairly heavy clay till, the sandy-silt will contain more sand than this underlying material. If underlain by a relatively fresh till, the sandy silt contains about the same or less sand than the till.

The cross-section of a longitudinal profile down part of the crest of an interfluve in Monroe County begins at the apparent topographic high of the modern surface for the immediate vicinity and continues down the crest of the interfluve (figure 18). It does not continue down to the present flood-plain.

The lines drawn to separate the different intervals in this profile and in all figures used to illustrate textural composition with depth are only as

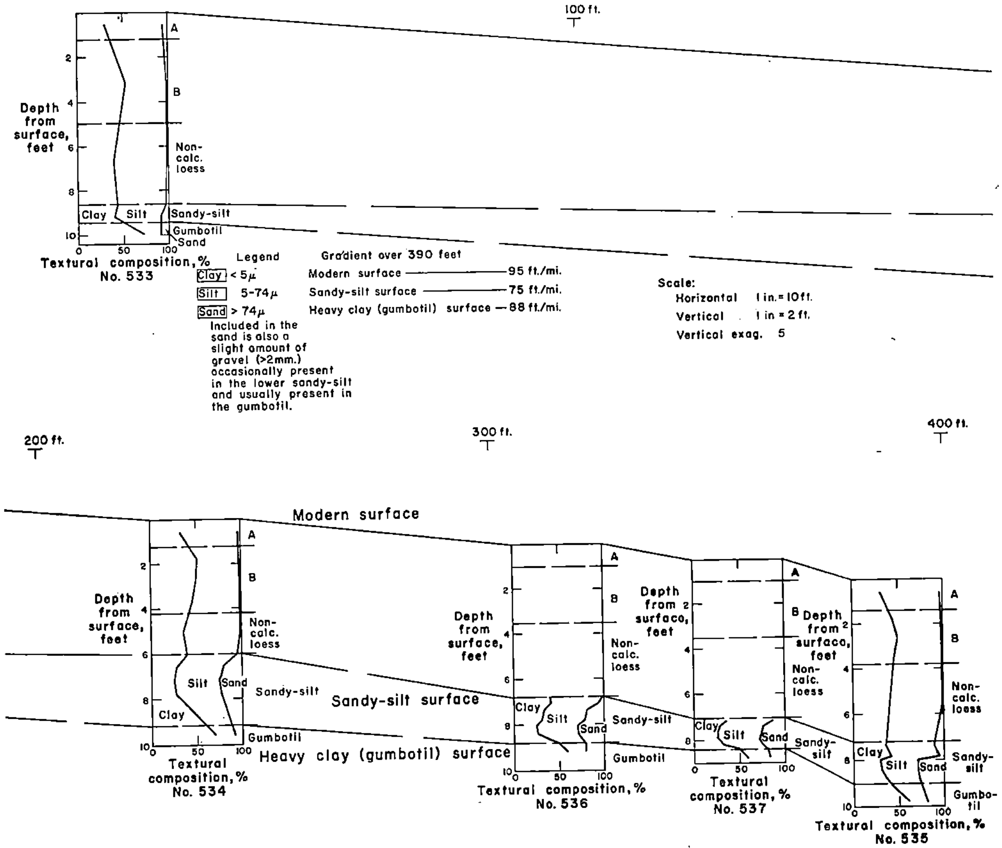


Fig. 18. Profile down crest of interfluve in Monroe County.

accurate as the sampling permits. In particular, the boundary of the loess and sandy-silt appears gradational and yet, even with detailed sampling, it would be considered sharp. From this profile one may draw the following conclusions:

Sandy-silt overlies gumbotil.

Thickness of the sandy-silt interval increases downslope from the highest position but not progressively.

Sand content measured at its maximum within the sandy-silt generally increases downslope.

Little or no gravel is within the sandy-silt.

The general feature is increasing sand, decreasing clay within the sandy-silt. In all profiles except No. 533 there is more sand and less clay in the sandy-silt (at the maximum and minimum points respectively) than in either the underlying gumbotil or overlying loess.

The gradient of both the modern surface and the heavy clay (gumbotil) surface approximate one degree (92 feet per mile).

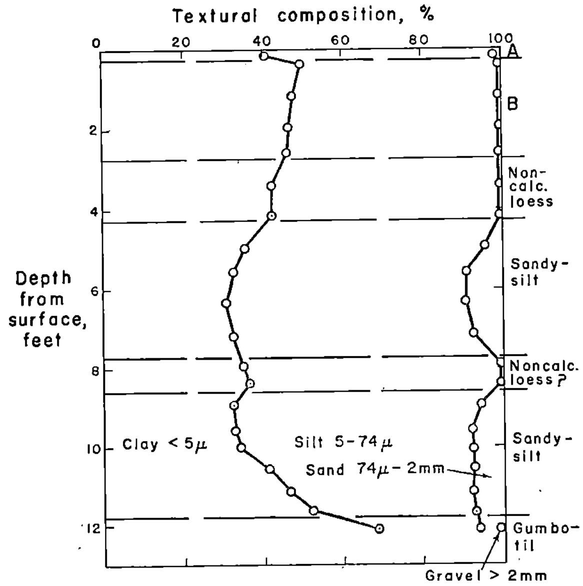
Upland topography in south-central Iowa may be defined as that at the highest elevation and usually with relatively flat interfluvial divides. The relief on an upland divide is usually limited to 5 to 10 feet. When viewed across a valley these divides appear to be at about the same elevation and are considered to be remnants of the Kansan till plain mantled with loess.

Auger holes were drilled into upland topography in Mahaska, Marion, Warren and Adair counties. In all bore holes, sediment similar in texture to the sandy-silt found in rolling topography was found lying above the gumbotil. In all profiles the sand content measured at the maximum point within this sandy-silt was less than that found in rolling topography, yet it was many times that found in the overlying loess (figure 19).

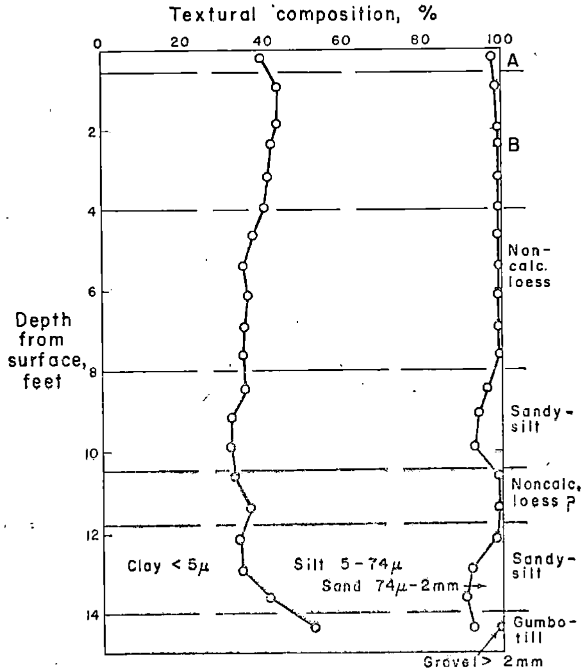
Based on map locations, the samples taken from two profiles in the NW¼ of NW¼ of NE¼, section 13, T76NR32W, Prussia Township, Adair County, are located on and above the Yarmouth-Sangamon surface[32]. Thin increments of loess, probably Farmdale, are in both these profiles. This interval was not found in the auger holes located farther east in Warren, Marion, and Mahaska counties, but this may be due to insufficient sampling.

Profile no. U_6 was obtained from an auger hole on the apparent high of the modern landscape, and No. U_5 was slightly lower (2 to 3 feet vertically) and approximately 40 feet (horizontally) from No. U_6.

These profiles show essentially the same type of texture with depth as that found in more rolling terrain, but with some differences. The main differences are that these profiles show a thin increment of loess between two sandy-silt intervals, and that the increase in sand and decrease in clay within the sandy-silt are much smaller than found in more rolling topography. The other important feature of these profiles is that the lower sandy-silt (above the gumbotil and below the thin increment of Farmdale



No. U_5 Adair Co.



No. U_6 Adair Co.

Fig. 19. Texture with depth of profiles No. U_6 and No. U_5 in Adair County.

loess) has a more gradational contact with the underlying gumbotil than that in rolling topography.

The lowest points of both these profiles are drawn from cumulative curves of the gumbotils taken from upland topography (figure 15). Cumulative curves of the sandy-silt on upland topography also show some irregularity as to distribution of points but not as markedly as those in rolling topography.

Without many more detailed borings over a small area (with which one could construct a contour map of the Kansan surface and compute the relief or micro-relief upon it), it is difficult to draw any inferences from these two profiles. It may be that No. U_6 is closer to the crest of a swell on the Kansan surface and No. U_5 is farther downslope or closer to the base of a swale on the buried surface. If this should be true and if the modern surface reflects in any way the buried topography of two paleosols on the Yarmouth-Sangaman surface then two characteristics of these profiles correlate with those shown by more detailed borings in rolling topography[32]. That is, the thickness of the sandy-silt interval may increase irregularly downslope from the highest point, and the maximum amount of sand within the sandy-silt appears to increase slightly downslope.

Physical Tests.

Textural, plasticity and classification data for the detailed study samples are available for all the major loess and till sites at the Iowa Engineering Experiment Station Soils Research Laboratory (table II). With no exception all of the till and loess analyzed rates as fair to poor for a subgrade material[40].

Chemical Tests.

Because the versenate test determines both calcium and magnesium ions,

TABLE II. TEXTURE, PLASTICITY, AND CLASSIFICATION OF THE DETAILED SAMPLES

Property	Glacial till				Loess				
	A	B	Non-calc.	Calc.	A	B	Non-calc.	Sandy-silt	Gumbotil
	416-1	416-2	416-3	416-4	528-1	528-2	528-4	528-7	528-8
Clay, % less than 0.005 mm.	27.5	39.0	35.0	37.1	29.5	43.0	39.0	25.0	75.0
Silt, % 0.005 to 0.074 mm.	30.0	26.1	31.5	29.0	69.1	56.5	60.8	51.0	12.5
Sand, % 0.074 to 2.0 mm.	34.0	32.9	28.6	30.2	1.4	0.5	0.2	24.0	12.0
Gravel, % more than 2.0 mm.	5.5	2.0	4.9	2.8	------	------	------	------	0.5
Liquid limit, %	38.4	44.2	38.2	38.2	33.8	48.8	50.1	24.5	87.1
Plastic limit, %	23.8	21.1	18.4	15.1	24.4	25.3	21.0	17.0	34.5
Plasticity index	14.6	23.1	19.8	23.1	9.4	23.5	29.1	7.5	52.6
B.P.R. Class. Engineering	A-6 (6)	A-7-6 (12)	A-6 (10)	A-6 (11)	A-4 (8)	A-7-6 (15)	A-7-6 (18)	A-4 (8)	A-7-5 (20)
Textural	Clay loam	Clay	Clay	Clay	Silty clay loam	Silty clay	Silty clay	Clay loam	Clay

irrespective of their source, the calcium carbonate percentages may not be true indications of the amount of calcite present, although it is believed that calcite contributes the majority of the ions. The calcareous till, No. 416-4 is the only sample with appreciable calcium carbonate. Upon close inspection in the laboratory, it was found that the matrix of this sample is not appreciably calcareous, rather that the calcite occurs in small (1 mm. or less) grains or concretions scattered randomly throughout the sample (table III).

All samples except the calcareous till are slightly to definitely acidic. The percentage of organic matter is insignificant except in the A horizons of both the till and loess. The range of values for the cation exchange capacity appears to vary directly with the amount of clay present.

PETROGRAPHY

Particle-Size Analysis.

Mechanical anlyses were performed on all samples by the hydrometer and sieving method, A.S.T.M. Designation: D122-54T as modified[9]. Except where indicated otherwise, the particle-size classification used in this report is that of the American Society for Testing Materials[2] (A.S.T.M. Designation: D422-54T) and the American Association of State Highway Officials[1] (A.A.S.H.O. Designation: M146-49). These two classifications use the following size limits: gravel greater than 2.0 mm; sand, 0.074 to 2.0 mm; silt, 0.074 to 0.005 mm; and clay, less than 0.005 mm. diameter. This classification closely approximates the Wentworth grade scale used by many geologists.

Glacial Till. The data showing the range of particle-size distribution for calcareous till outcropping across southern Iowa represent 71 samples taken from roadcuts and auger holes from 34 different sites (figure 3). Sampling depth varied from 4 to 40 feet below the surface, but in most instances, the maximum sampling depth was at least 16 feet. A composite sample of all the calcareous till was taken at each site, along with numerous samples of 6 inch increments from each site.

Considering the wide geographic spread of the area and the random sampling system, it appears significant that the calcareous till is relatively

TABLE III. RESULTS OF CHEMICAL TESTS

Property	Glacial till				Loess			Sandy-silt	Gumbotil
	A	B	Non-calc.	Calc.	A	B	Non-calc.		
	416-1	416-2	416-3	416-4	528-1	528-2	528-4	528-7	528-8
Calcium carbonate[a]	0.6	1.0	1.0	3.5	0.5	1.4	1.5	1.0	0.8
pH	6.8	6.7	6.4	7.4	5.9	5.6	5.6	6.8	6.5
Organic matter[a]	3.4	1.1	0.5	0.8	1.7	0.3	0.2	0.1	0.2
Cation exchange capacity[b]	15.7	17.5	17.2	14.8	14.7	24.6	23.5	11.3	45.3

[a] Percent by weight of oven-dry soil
[b] Milliequivalents per 100 grams of oven-dry soil

uniform in particle-size distribution. It is certainly poorly sorted and, as mentioned previously, it does contain conspicuous sand and gravel lenses and pockets. However, for general purposes, the Kansan till in southern Iowa may be roughly divided into thirds: one each of clay, silt, and sand and gravel. The average particle-size distribution (figure 2) for the 71 samples is 34% clay (25-45%), 30% silt (10-52%), 33% sand (15-48%), and 3% gravel (0-8%).

No conspicuous regional trend is evident in the distribution of the till texture. In fact, in southwestern Iowa, the maximum variation in texture was between two sites only a mile and a half apart[28], and in south-central Iowa the maximum variation was in two adjacent counties. Except for the more obvious silt, sand, and gravel lenses, the vertical variation in the till mass is slight (figure 10).

Gumbotil. Eight samples considered to be gumbotil were taken from roadcuts or auger holes. The sites were usually on spurs of upland divides extending out into more rolling topography. This gumbotil in all instances was buried by younger sediment and is immediately overlain by sandy silt. The particle-size distribution curve shows a fairly wide range (figure 15). True gumbotils are thought to be extremely weathered till, and so should show the same general type of cumulative curve as the till except for a higher percentage of fine material. These samples show this relationship (figure 15).

Mineralogical Analyses.

Megascopic analysis. The coarse sand and gravel portion of the glacial till contains a variety of rock types and minerals, but the following are most commonly observed: granite, granodiorite, quartzite, slate, basalt, greenstone, gneiss, schist, quartz, and chert.

Microscopic analysis. Table IV is a summary of accumulated petrographic data[28]. These mineral determinations were made with a Leitz petrographic

TABLE IV. MINERAL COMPOSITION OF KANSAN TILL, % BY WEIGHT AND % OF SELECTED SIZE FRACTION

Mineral	409-3 Ca. till % by weight	416-4 Calc. till % of two size fractions		425-5 Calc. till % of one size fraction	429-4 Non-calc. till % of one size fraction
	5μ-2000μ	20μ-44μ	105μ-149μ	20μ-44μ	20μ-40μ
Quartz	37	62	63	47	53
Total feldspar	13	20	16	25	24
Carbonates	2	5	6	17	7
Miscellaneous light	1	3	3	3	4
Miscellaneous heavy	3	4	5	4	5
Iron oxide concretions	3	2	4	2	4
Altered and not identifiable	6	4	3	2	4
Quartz/feldspar ratio	2.9/1	3.1/1	3.9/1	1.9/1	2.2/1
Clay, minus 5μ	37	----	----	----	----
Gravel, over 2000μ	2	----	----	----	----

microscope by determining grains along traverses. At least 300 grains were determined in each particular size fraction. The data identifying numerous size fractions between 5 micron and 2.0 mm., may be the most pertinent, for this gives the mineral composition by weight of the whole sample[28].

The dominant miscellaneous light minerals are mica and chert; the dominant miscellaneous heavy minerals are amphibole, pyroxene, zircon, tourmaline, and chlorite. In all samples, quartz is the dominant mineral, and feldspar is second in abundance (table V).

A seemingly poor correlation between field observation and laboratory analyses is illustrated by the various carbonate percentages, which vary from 2% by weight of whole till to 17% of selected size fraction for till described in the field as calcareous.

The gravel fraction of the glacial till was observed at a number of field locations, and the following rocks and minerals appear to predominate: quartz, chert, quartzite, granite, granodiorite, slate, greenstone, basalt and weathered gneisses and schists. Many other rocks may be found in the till, and varying degrees of weathering may be observed on the less resistant varieties. A red quartzite similar to the Sioux Quartzite which outcrops in northwestern Iowa may be singled out as a rock which occurs throughout the till.

The sand-size material in both the upper loess and the intermediate loess of profiles Nos. U_5 and U_6 consisted almost wholly of brown or black concretions of iron oxide.

In sharp contrast with the iron concretions in the loess, the mineralogy of the sand-size material of both the upper sandy-silt and the lower sandy-silt above the gumbotil consisted of a very high percentage of quartz with minor amounts of light-colored feldspar and mica (muscovite).

The sand content of the gumbotil was similar in mineralogy to that in the sandy-silt, and the gravel fraction in the base of both these profiles was quartzite.

TABLE V. MINERAL COMPOSITION (% OF SELECTED SIZE FRACTION)

Mineral type	Till, calc. 416-4		Loess, non-calc. 528-4		Sandy-silt 528-7		Gumbotil 528-8	
	20-44 μ	105-149 μ	20-44 μ	74-840 μ	20-44 μ	105-149 μ	20-44 μ	105-149 μ
Quartz	62	63	45	18	71	84	71	79
Total feldspar	20	16	32	7	19	5	17	11
Carbonates	5	6	----	----	----	----	----	----
Miscellaneous light	3	3	4	3	2	2	2	1
Iron oxide concretions	2	4	2	66	2	4	4	3
Miscellaneous heavy	4	5	13	4	2	2	2	2
Altered and not identifiable	4	3	4	2	4	3	5	5
Quartz/feldspar ratio	3.1/1	3.9/1	1.4/1	----	3.7/1	16.8/1	4.2/1	7.2/1

Microscopic analysis. Table V presents the various percentages of the mineral or mineral type found in the selected size fractions of the sediments studied. In all but the coarser fraction of the loess, quartz is the dominant mineral, and feldspar is second in dominance. Iron concretions dominate the coarser fraction of the loess.

Miscellaneous light minerals include all those expected to float in bromoform (sp. gr. = 2.87) except quartz, feldspar, and carbonates. The dominant light minerals are chert and mica. Miscellaneous heavy minerals include all those expected to sink in bromoform except iron concretions. The dominant heavy minerals are amphibole, pyroxene, and zircon with minor amounts of garnet, tourmaline and others.

Altered minerals include many which may have been classified as feldspar, but surface staining and alteration made a more positive identification difficult. The quartz/feldspar ratio is higher for the coarser fractions in all sediments. The ratio in the gumbotil is appreciably higher than that in the calcareous till and is extremely high in the coarser fraction of the sandy-silt.

X-ray analysis. The X-ray study was intended primarily to cover only the clay minerals and those minerals in the finer fractions. All curves except the bottom one in each figure (undispersed whole sample less than 44 microns) came from material which was dispersed with sodium metaphosphate and then elutriated prior to analysis.

In figures 20, 21, and 22 the first prominent reflections in the finer fractions (and in the undispersed whole sample, less than 44 microns) are between 16.7 and 17.3 Angströms, and are interpreted as first order basal spacings or glycolated montmorillonite. Unglycolated samples had first reflections that varied between 10 to 18 Angströms in a broad band, or were prominent at 14.7 Angströms—again suggesting montmorillonite.

The 10.0 to 10.16 Angström spacing is the first order reflection of an illite-group clay mineral, or muscovite. This is prominent in all but the minus 2 micron fraction and in the very coarse fractions. The presence of mica and mica-like clay minerals is thus established in the fractions from 5 to 105 microns.

The 7.13 and 3.57 Angström spacings are diagnostic of kaolinite. Since these spacings are also diagnostic of chlorite, some differentiation is necessary. On being heated to 600°C, kaolinite tends to lose its crystalline character, but chlorite is little affected[19]. After several fractions were heated, the elimination or extreme decrease of the 7.13 Angström reflection indicated the presence of kaolinite.

In the coarser fractions (mainly 5 to 74 microns) the first prominent reflections are between 14.24 and 14.72 Angströms and are interpreted as first order basal spacings for chlorite or vermiculite. A distinction may be made between these two minerals by heating the sample at 700°C, at which

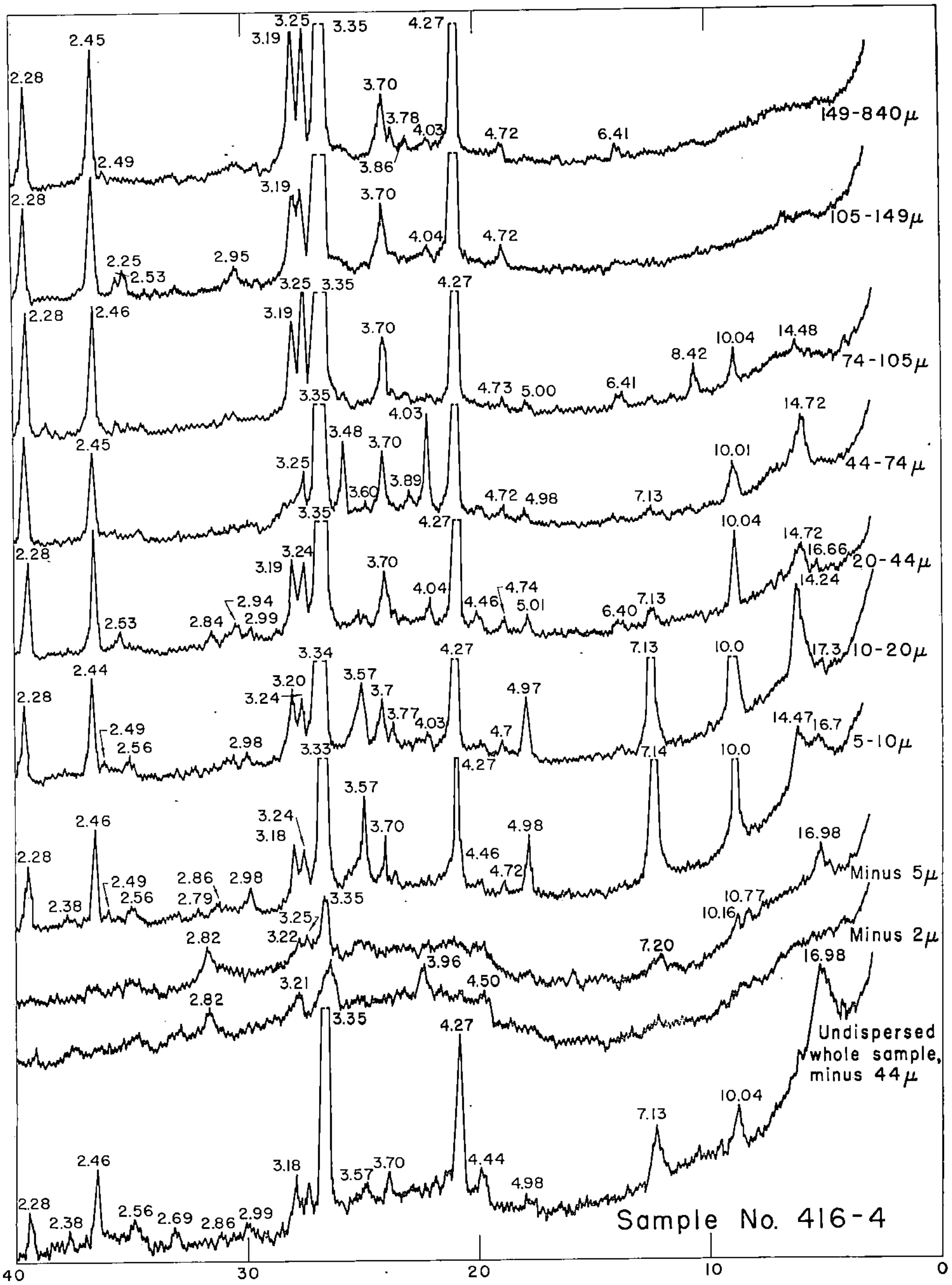


Fig. 20. X-ray diffraction curves for several size fractions of sample No. 416-4.

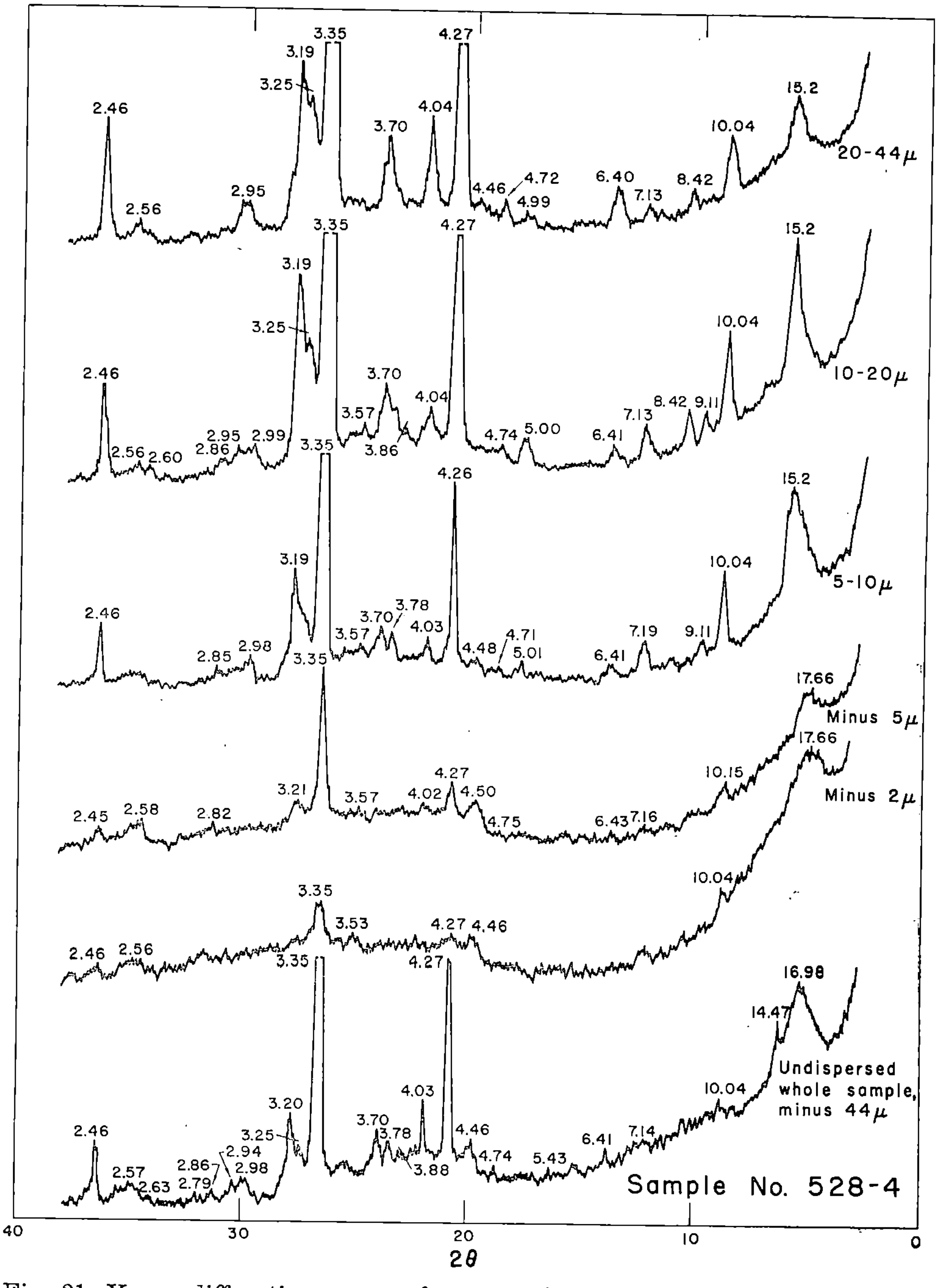


Fig. 21. X-ray diffraction curves for several size fractions of sample No. 528-4.

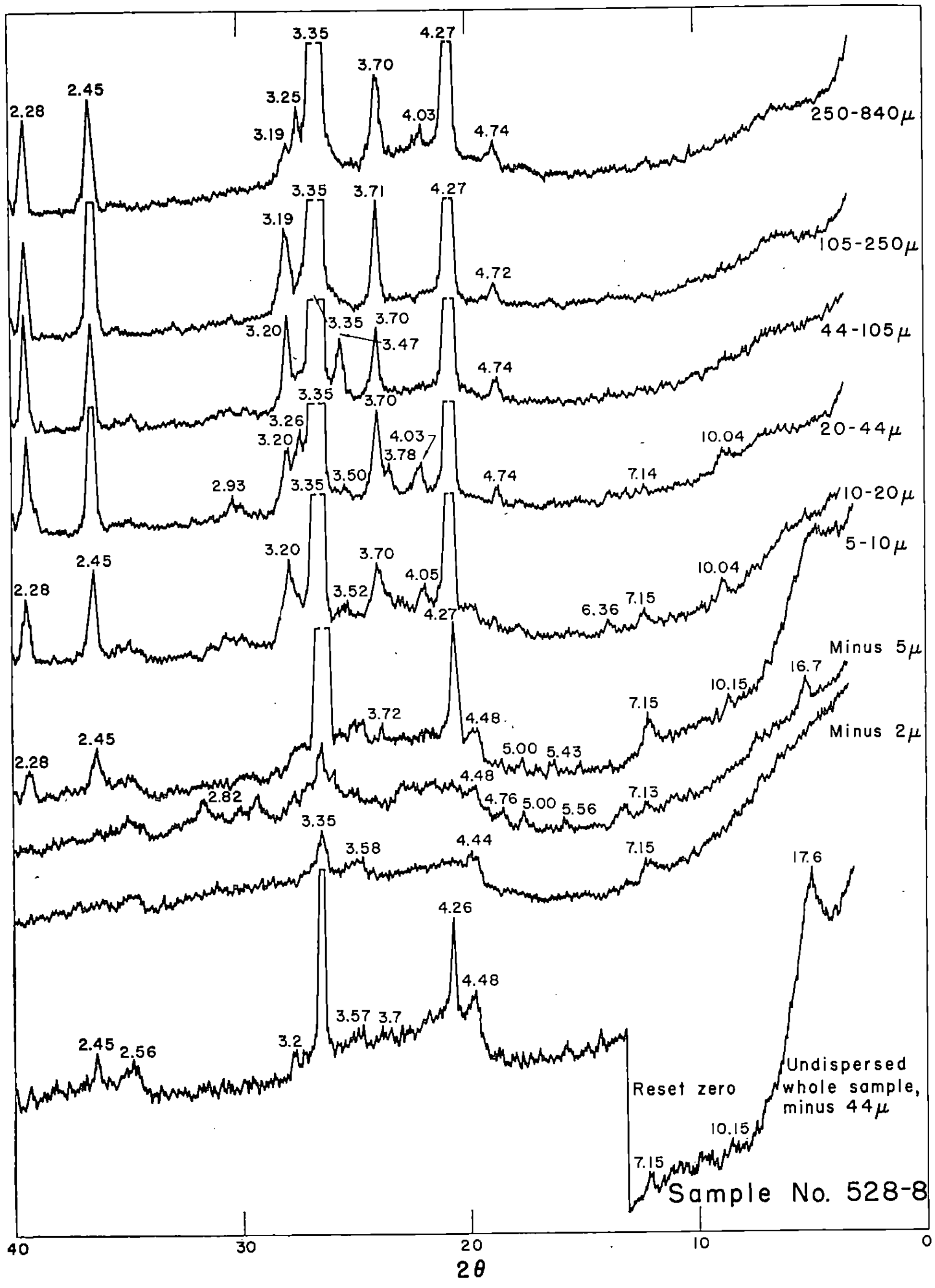


Fig. 22. X-ray diffraction curves for several size fractions of sample No. 528-8.

temperature the 14 kx line of vermiculite is replaced by a line at 9.3 kx, representing the basic talc-like layers[6]. Several fractions were heated to this temperature and, upon X-raying, it was observed that the 14 Angström was either reduced or completely eliminated, and that weak or no reflections were observed at spacings from 8.6 to 9.3 Angströms. Vermiculite, minor chlorite, and the possibility of mixed layer clays and hydrous micas were found in these samples. Reflections in the coarser fractions are mainly for quartz, feldspar, and mica.

A peculiarity is noted in the diffraction curves for the finer fractions analyzed. In the minus 2 micron curve for No. 416-4 (figure 20), most of the material in this fraction appears amorphous, although there are some weak reflections for quartz and feldspar. Since clay mineral reflections are prominent in the undispersed whole sample, less than 44 microns, it was thought that the clay peaks would be very prominent. It may be that the method of preparation is responsible for this lack of clay peaks in the finer fraction, but possibly only a small percentage of actual crystalline clay minerals may be in the clay-size fraction.

ENGINEERING PROPERTIES

The Atterberg limits and an engineering classification[40] of numerous calcareous glacial till samples are given in table VI. The general rating of the glacial till as a subgrade material is fair to poor.

TABLE VI. ATTERBERG LIMITS AND ENGINEERING CLASSIFICATION OF CALCAREOUS GLACIAL TILL

Sample No.	Liquid Limit	Plastic Limit	Plasticity Index	Engineering Classification
404-4	38.3	15.9	22.4	A-6(12)
406-3	36.0	15.9	20.1	A-6(5)
407-3	43.2	14.6	28.6	A-7-6(16)
409-12C	42.4	20.5	21.9	A-7-6(11)
411-4C	41.8	14.9	26.9	A-7-6(14)
413-4	35.2	15.0	20.2	A-6(11)
414-6	35.0	16.0	19.0	A-6(10)
415-4	39.6	14.6	25.0	A-6(14)
416-4	38.2	15.1	23.1	A-6(12)
417-3	33.8	14.0	19.8	A-6(10)
418-3	44.8	15.4	29.4	A-7-6(16)
419-4	31.0	13.3	17.7	A-6(8)
420-3	38.8	17.6	21.2	A-6(11)
421-4	30.9	12.6	18.3	A-6(8)
422-4	28.9	14.1	14.8	A-6(7)
423-5	40.9	17.3	23.6	A-6(12)
425-5	29.0	17.0	12.0	A-6(7)
426-6	36.4	16.4	20.0	A-6(11)
427-5	29.9	15.1	14.8	A-6(9)
429-4	27.6	14.7	12.9	A-6(6)
430-6	29.9	14.3	15.6	A-6(7)
432-4	28.1	14.1	14.0	A-6(7)
433-7	29.3	12.3	17.0	A-6(8)

Clay minerals.

Differential thermal analysis. Differential thermal curves for the minus 44 micron fractions of several glacial till samples are given in figures 23 and 24. Endothermic reactions are indicated by downward peaks in the curves, exothermic reactions by upward peaks.

The curves suggest that illite and montmorillonite are the dominant clay minerals in the samples. The presence of a montmorillonite group mineral is indicated by the relatively large absorbed water reactions at 100 to 200°C. Illite appears to be the dominant clay mineral in most samples because of the pronounced endothermic reaction at 550°C., which indicates the loss of OH^- structural water.

The presence of vermiculite is suggested by a slight deflection of the dehydration curve at 175 to 200°C. The slight exothermic peaks at about 300°C. are caused by oxidation of organic matter. The most clearcut endothermic peak for quartz inversion (570 to 580°C.) occurs in the A horizon sample No. 416-1. In this horizon weathering has tended to concentrate the more resistant minerals. Calcite and minor amounts of dolomite are strongly indicated in the calcareous till samples.

PROBLEMS

Some of the problems which have been raised in the studies of glacial till and other Pleistocene deposits are the following:

1. It is correct to assume that the texture of at least the upper few tens of feet of glacial till is consistent with the texture presented, then the mechanism of till deposition must be considered. Would material with so little

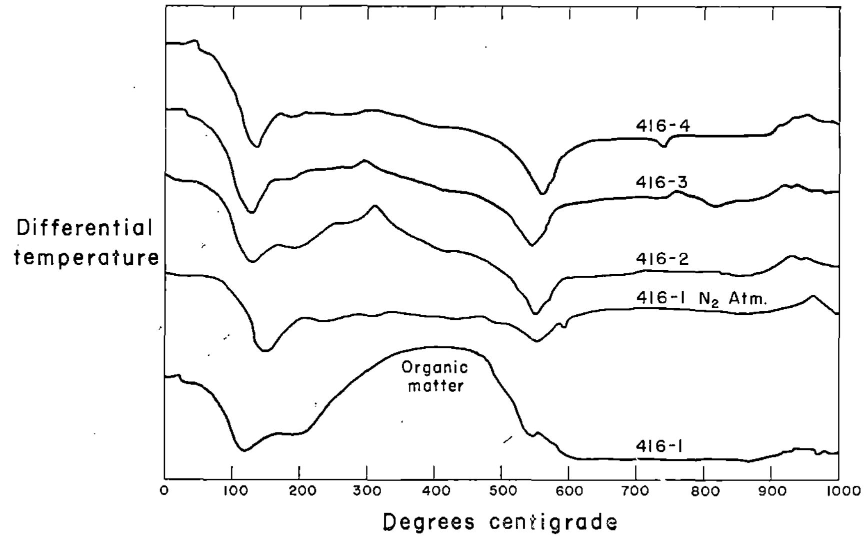


Fig. 23. Differential thermal analysis curves for the four horizons of detailed sample site No. 416.

areal or vertical variation in particle-size distribution be deposited by lodgement under an ice cap?

2. The origin of sandy silt is yet to be explained on the higher interfluves and where it overlies gumbotil. This sediment has been observed between the till (or gumbotil) and the clayey silt (loess) in both the more rolling terrain and on the flatter uplands.

One investigator who has worked on the sandy silt (which he terms pedi-sediment of translocated sediment) in Adair County, in southern Iowa, has related its origin to a process of landscape evolution[32]. According to this investigator, the pedi-sediment is derived from till and is formed during the multi-cyclic erosion (pedimentation)of the pre-loess glacial till landscape. No pedi-sediment was observed on the highest surface in that area, the Yarmouth-Sangamon, which is identified as a highly weathered, but little eroded, relict of the Kansan drift plain now covered by loess. Thus no

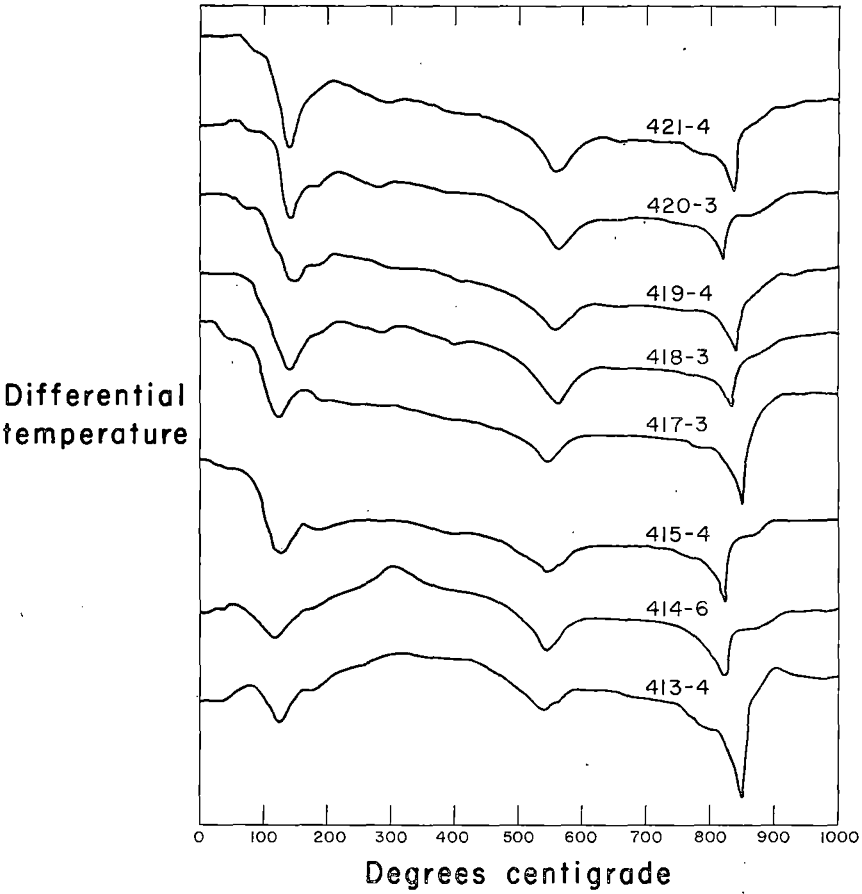


Fig. 24. Differential thermal analysis curves for several calcareous till samples.

pedi-sediment was over the now-buried heavy clay soil or gumbotil found on this Yarmouth-Sangamon surface.

However, borings in the NW¼ of NW¼ of NE¼, Section 13, T 76 N, R 32 W, Prussia Township, Adair County, Iowa, revealed sandy-silt above gumbotil. Based on map locations, it is believed this sediment was located on and above the Yarmouth-Sangamon surface[32].

Auger holes were also bored into upland topography in Mahaska, Marion, and Warren counties, and in all the borings a sandy silt was found above the gumbotil and below the loess. Several borings down the crest of an interfluve in Monroe County also revealed a sandy silt above gumbotil.

In section U_5 only the upper four feet might be called loess, but in U_6 (two feet higher on the modern landscape and forty feet horizontally from U_5) eight feet might be called loess. However, without careful field observation and detailed sampling, the material in U_5 down to a depth of about 12 feet, and in U_6 down to a depth of 14 feet, might be called loess. The use of the word *loess* raises a problem also. The texture of this deposit changes with depth, and there is a thin increment of clayey silt, lying between two sandy silts, which may have been identified[32] as Farmdale loess. Not only does the texture of the section vary, but so does the mineral composition of the sand-size material. The clayey silt (loess) contains some sand-sized sediment, but it is made up principally of authigenic iron concretions. In the sandy silt, the sand-sized particles increase; these sand grains are mainly quartz and feldspar, as well as some iron concretions. Obviously, the sand in the upper sandy silt could not have been derived from the underlying clayey silt or Farmdale loess. Thus, the origin of the sandy-silt, as well as the use of the word *loess* to mean wind-deposited silt, both raise problems.

3. The third problem to be raised concerns the clay mineralogy of the glacial till. What percentage of the clay-size fraction is made up of recognized crystalline clay minerals?

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GEOLOGIC AND ENGINEERING PROPERTIES OF TILL AND LOESS, SOUTHEAST IOWA

by

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The field work on the till and loess of southeast Iowa was conducted in the lower three tiers of counties in the state. This area includes all of Keokuk, Washington, Louisa, Des Moines, Lee, Henry, Jefferson, and Van Buren counties, and parts of Wapello and Davis counties.

Till of Nebraskan age covers much of the bedrock surface of the southeast portion of Iowa. Though now covered by loess and drift of later stages, several good exposures showing the relationship to the over-lying Kansan till can be found in Denmark and Washington townships in Lee county. The total thickness of Nebraskan drift in southeast Iowa has been estimated as somewhat more than 100 feet with a thinning trend toward the southeast[19].

Kansan drift is extensively exposed in the numerous valleys and road cuts in this region. It is widespread and can be found at all locations other than the broad floodplains of the major drainage systems. The upper surface of the Kansan drift in parts of Scott, Muscatine, Louisa, Des Moines, and Lee counties is overlain by drift of Illinoian age. Kansan gumbotil is occasionally found under the Illinoian material. Gumbotil surfaces are more extensively exposed northwest of the Illinoian contact, and can be found on the interfluve divides just below the upland surface in road cuts as well as in borings which penetrate the loess cover.

Illinoian drift which is found only in extreme southeast Iowa, is in an arcuate lobe which was apparently the terminus of a southwesterly moving ice sheet (figure 1). The average thickness of the Illinoian drift is approximately 30 feet.

Loess covers the southeast Iowa region except in local areas where erosion has stripped it away. A definite thickening trend of the loess was noted in traverses extending from the west boundary of Keokuk County to the northeast bank of the Iowa River, slightly above the town of Wapello. This thickening trend has been investigated and tentatively mapped[8, 15] (figure 2). Loess is primarily on the extensive upland surfaces or interfluvial divides. These divides are particularly well exemplified in Keokuk and Washington Counties along Highway 78, where level areas approaching eight square miles are not uncommon, and along Highway 34 from New London to Burlington. Loess is found also on the flanks of the major stream divides and upon all the lesser ridge tops, progressively thinning downslope due to erosion. This thinning is in an east-west direction below the ridgetops[27]. In the major drainage channels all loess has been removed. In minor channels and near the base of the lesser ridges the loess is thoroughly mixed with the pre-existing till or alluvium, and therefore is not recognizable as a typical loess deposit.

TILL SOILS

The till soils sampled in southeast Iowa belong to the Grey-Brown Podzolic great soil group. More specifically they belong to the Clinton-Lindley or Weller-Lindley soil association. These two associations make up 3,700 square miles, or 6.6% of Iowa's total land surface[31]. The Lindley soil of

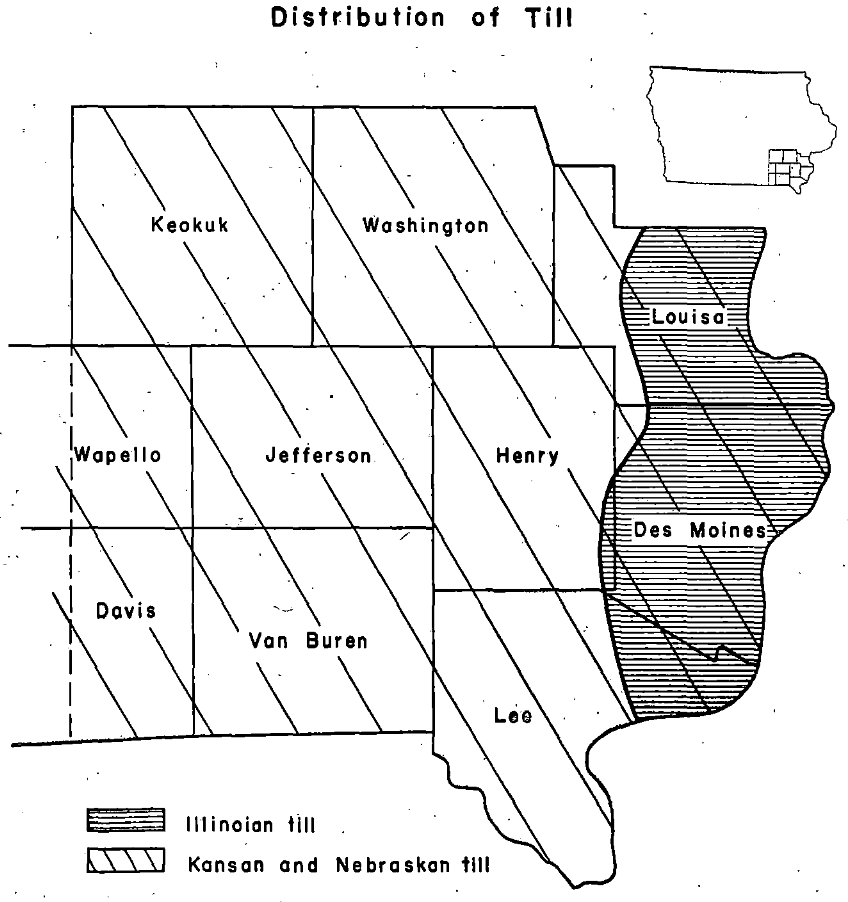


Fig. 1. Distribution of Illinoian, Kansan, and Nebraskan till in southeastern Iowa.

either soil association area has developed under forest cover upon the underlying till of Kansan age.

The soil samples from many till areas appear much like the characteristic Lindley profile except for horizon color. The B horizon commonly is conspicuous in that it appears as a distinct dark-reddish brown to orange-brown horizon. This soil is interpreted as a variety of the normal Lindley series, formed prior to loess deposition in a somewhat warmer climate, strongly oxidized, and subsequently covered by a few feet of loess. These B horizons sometimes called "ferretto" zones, appear as distinct bands in road cuts, or as large irregular patches of several acres or more on slopes with excessive erosion.

Deviation from the normal Lindley profile commonly occurs. Where the loess cover has not been completely removed by erosion the A horizon may develop in part from this material. Where erosion has been more severe, the gradational agents usually have caused a mixing of the loess and underlying till. One can find the Lindley series developed in the normal manner upon glacial till, but with a composite A-horizon. This upper composite horizon may be determined from an analysis of the textural gradation curve for the sample in question. Bimodal sorting is generally indicative of a composite origin, and the resulting soil horizon resembles a sandy silt.

This poorly sorted sandy silt may be evidence of a weathering cycle in which a "pedi-sediment" or alluvial blanket forms, as the result of lateral slope erosion[27].

The tills exposed within the southeast Iowa area may best be described

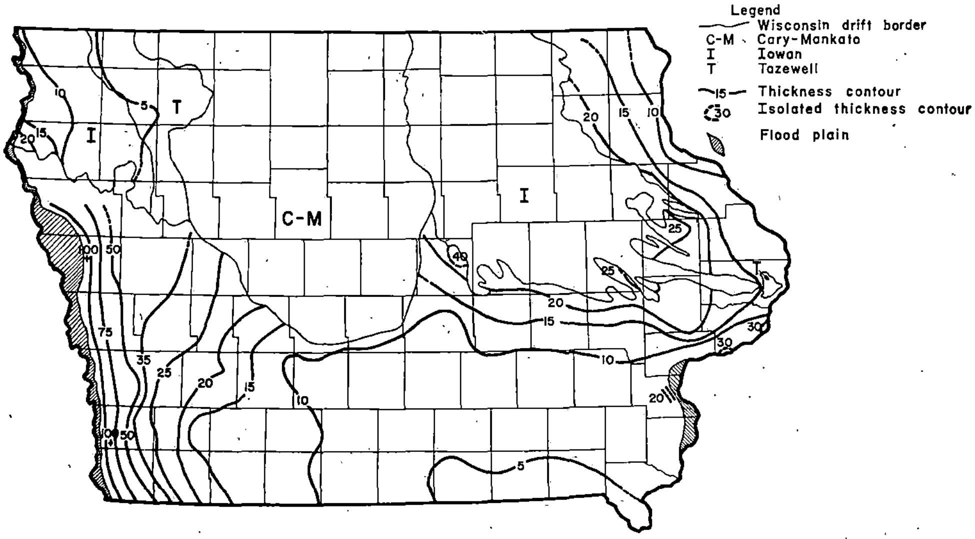


Fig. 2. Map showing loess thickness in Iowa.

as a succession of unconsolidated sedimentary deposits superimposed on one another. As they are widespread and mappable units they may be thought of as being formationlike in character. However, they are remarkably non-uniform horizontally; that is, they change abruptly both texturally and mineralogically within a relatively short distance.

It has been said that till is "homogeneous in its heterogeneity", and field studies unquestionably support this statement. Within a lateral distance of not more than a hundred yards, sizeable deposits of coarse gravel, sand lenses, and pockets of fine silt are not uncommon. These same relationships hold true in vertical traverses. Though at first surprising, these phenomena can be explained more easily if one thinks of the nature of the medium of deposition. Pushed and carried by a glacier, these materials were randomly deposited, then picked up and deposited again and again. Meltwater streams coursing from the glacier meandered across the sediments, reworking them still further, adding first coarse debris, then fine silts. The non-uniformity of these deposits should be the rule rather than the exception.

The A horizon is most commonly a friable brown to dark brown silt loam[36]. The soil peds are granular to somewhat subangular blocky. Locally the A horizon, light gray in color, exhibits a platy structure. This structure is characteristic of soils developed under forest vegetation. Care must be taken, however, not to confuse the fine plate-like structure with a pseudo-platiness caused by slumping or by the sampling instruments themselves.

The B horizon, at least in the Lindley series, is composed of angular blocky peds and has an orange-brown to red-brown cast. The higher clay content of this horizon may exhibit itself in the form of waxy coatings on the surface of peds. These coatings are known as "clay skins" and are found only in the zone of maximum clay accumulation. Texturally, the B horizon is a clay loam to clay.

Accumulations of coarse gravel-sized fragments may be at the top of the B horizon, especially where the overlying A horizon has a composite origin. These stone-lines have been interpreted as lag-gravel concentrates formed during one of the cycles of landscape evolution[27].

C_1 horizons in till generally show little or no ped structure. This horizon is composed of coarse blocky fragments having a yellowish brown color. Iron and manganese concretions are numerous and give a mottled appearance to the till. Carbonate concretions occasionally occur within this oxidized horizon.

The unoxidized calcareous C_2 horizon has a massive jointed structure. Colors range from yellowish brown through gray and brown or gray. Moist surfaces may exhibit a pronounced bluish cast. Carbonate concretions are numerous throughout but are concentrated in a zone just below the C_1 contact. Calcite and selenite have been observed on sheet-like plates filling the joints. Manganese and iron in the ferric state stain the till along the joint systems and also surround the sand lenses as a thin "shell".

Loess Soils.

The Weller and Clinton series are gray-brown podzolic soils whose solum has developed from the loess parent material. They are on the undulating uplands and on the shoulders of the flat interfluvial divides, differing mainly in their slopes of 1 to 5% and 4 to 8% respectively. The profiles of Weller and Clinton soils are similar, except that Clinton soils are generally somewhat higher in clay content.

The Grundy series is a Brunizem formed from loess on the rolling uplands where slopes range from 1 to 7%. The solum of Grundy soils is deeper and darker than either the Clinton or Weller soils. The B horizon is high in clay and is rather poorly drained.

In the field, the C horizon of most of the loess soils appears as a light bluish-gray silty loam to clay loam. Frequent orange mottles of oxidized material and dark spots believed to be manganese concretions are found throughout the horizon. The dark concretions often spread into elongate ribbons when abraded by the sampling instruments[31].

A horizons of loess derived soils vary significantly in color. These color changes are most noticeable between those soils classed as Brunizems (grass vegetation) and gray-brown podzols (forest vegetation). The soils developed under grass on the gently undulating uplands have dark brown to black A horizons at least one and possibly two feet thick. Their counterparts under forest cover are usually a chalky gray to light brown. Variations in the B horizons are less noticeable, especially when the cut surface is dry. Predominant colors are brown to yellow-brown, occasionally mottled with strong red spots. Clay skins are not seen as frequently as in till derived soils. B horizon textures range from clay loams to clays.

The C horizons of the loess is practically uniform in color and texture throughout the area. Predominantly a light yellowish brown on dry surfaces, the loess commonly exhibits a blue cast on freshly scraped surfaces and in auger samples. Mottling within the C horizon is common, but on a different scale than that in the B horizon. Large patches covering several square inches are not uncommon. These mottles range in color from dark brown to a brilliant orange.

Thin bands of this same brilliant orange color can be seen at times running roughly parallel to the surface configuration. Their origin is thought to be related to fluctuations of the water table.

STRATIGRAPHIC RELATIONSHIPS

Wisconsin loess in the sample area is in a widespread deposit overlying three stratigraphically different till deposits. The loess is remarkably uniform in appearance and textural composition, though minor modifications occur due to difference in slope, drainage, and vegetation. Clay fractions of the loess are most affected by these factors. Occasionally the fine sand fraction varies slightly in those samples obtained immediately east of major floodplains, commonly increasing 3 to 7 percent. This enrichment may have been caused by eolian transportation of the sand fraction from the floodplain or from sand bars in nearby rivers.

Below the loess, and at varying depths, a sandy silt is usually found. This silt is both on sloping and extremely flat terrain, appearing in road cuts as a conspicuous light gray band. The contact with the overlying loess is gradational, though within a range of no more than 5 to 10 inches. Vegetation often grows more rapidly in the contact zone than in the material above or below. A further means of identification is that the sandy silt contains numerous manganese concretions in addition to the sand fraction. These concretions may stand out above the surface, supported on minute pedestals of silty material.

The uppermost and youngest till is of Illinoian age, found only in the extreme eastern portion of the area. The upper surface of the Illinoian till is commonly a markedly weathered zone in contact with the overlying loess or sandy silt. The brownish red to blue-gray till has a high clay content and

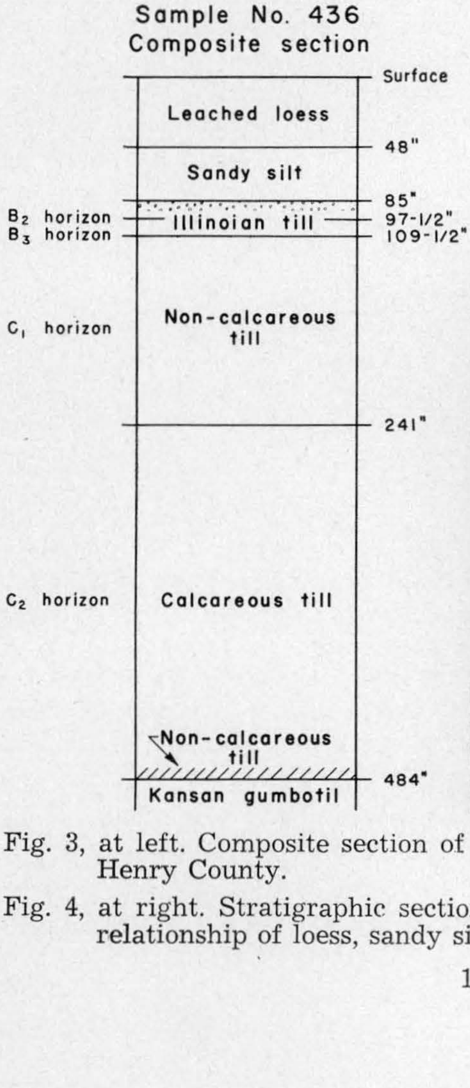
TABLE I. QUATERNARY STRATIGRAPHY OF THE MISSISSIPPI VALLEY[11].

Lower Valley		Upper Valley		
Formations	Events (Fisk, 1938)	Stages (Kay, 1944)	Substages	Materials (Leighton & Willman, 1950)
Recent	Alluviation	Recent		
	Valley Cutting	Wisconsin	Mankato	Loess* Till
			Cary	Loess* Till
Prairie	Alluviation	Peorian	Tazewell	Loess* Till
	Valley Cutting	Iowan	Iowan	Loess* Till
			Farmdale (Pro-Wis.)	Loess†
Montgomery	Alluviation	Sangamon		Gumbotil
	Valley Cutting	Illinoian	Buffalo Hart Jacksonville	Till
			Payson Loveland (Pro-Ill.)	Loess†
Bentley	Alluviation	Yarmouth		Gumbotil Till
	Valley Cutting	Kansan	Pro-Kansan?†	Loess†
Williana	Alluviation Valley Cutting	Aftonian Nebraskan		Gumbotil Till

* Peorian Loess where not differentiated.
† Recognized in lower valley by Leighton & Willman, 1950.

usually a gravelly band at the plane of contact with the sandy silt. This surface is considered to be evidence of the long weathering interval known as the Sangamon Interglacial Period. Below the weathered zone the clay content decreases; the soil peds increase in size, become blocky, then grade into a massive structure. In some deep sections the unoxidized and unleached calcareous till may be found. An excellent location at which to observe a complete section of this type is in the NE¼NE¼ sect. 34, New London Township, Henry County (figure 3).

The intermediate till in the sample area is of Kansan age and can be found throughout the entire area. The upper surface usually has the same properties as the weathered zone of the Illinoian till and represents the Yarmouth weathering interval. Not infrequently the weathered zone is a bluish black to light gray unctuous clay, locally called "gumbo." This gumbotil represents a very high degree of weathering in regions of poor in-



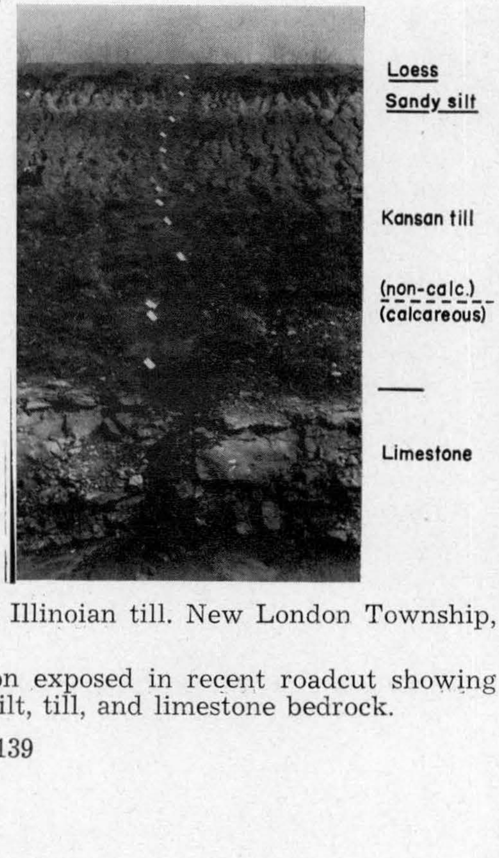


Fig. 3, at left. Composite section of Illinoian till. New London Township, Henry County.

Fig. 4, at right. Stratigraphic section exposed in recent roadcut showing relationship of loess, sandy silt, till, and limestone bedrock.

ternal drainage; consequently it is found in rather flat terrain which formerly was a swale on the old undissected Kansan plain. The normal sequence of oxidized and leached, oxidized and unleached, and unoxidized and unleached till lies below the weathered zone.

Between the intermediate Kansan and the Nebraskan till, reddish, strongly oxidized gravel deposits may be found. These deposits are designated as Aftonian gravels[18]. Apparently these gravel deposits developed as a lag concentrate on the Nebraskan till surface during the Aftonian interglacial weathering period.

The oldest till in the area is of Nebraskan age. This till is infrequently exposed due to the thickness of the overlying deposits, and lies upon the bedrock. One exposure is northwest of Denmark in Lee County[18].

Since all disturbed bulk samples are remarkably similar, there is no absolute method of determining the exact till. To identify a given sample more positively one must first examine it "in situ", noting relationships with the overlying materials. For example, to identify a sample as Kansan till, there must be evidence of another stratigraphically lower till, separated by a stone line, gumbotil horizon, or some other type of weathering zone. If these relationships are not evident at the sample location, they must be sought for in the vicinity and traced into the sample area. In this manner, Kansan till lying on bedrock locally scoured of Nebraskan till would not be identified as Nebraskan.

GEOMORPHOLOGY

Surface Features.

The topography of southeastern Iowa has been affected by two major phases of deposition in addition to the action of erosion. Bedrock surfaces are covered by as much as 200 feet of glacial till and 25 feet of loess; therefore they cease to influence modern landscape evolution. The glacial till, deposited in two or three stages, covered and filled the depressions in the bedrock and undoubtedly left an undulating to gently rolling surface much like that of the Cary-Mankato drift of north-central Iowa. The only moraine in southeastern Iowa is the low broken ridge best developed just west of West Point, Lee County, which marks the limit of the advance of the Illinoian glacier. Erosion leveled much of the surface of the glacial deposits, forming the so-called "till plain." Loess, presumably derived from the Missouri floodplain and local areas, at one time blanketed the entire region.

The modern landscape now exhibits a topographic surface which ranges from a virtually unmodified loess covered till plain to steeply rolling or hilly terrain. The extensive "flats" or the "interfluve divides" are considered remnants of the former extensive till plain. Steeply rolling surfaces which exhibit the stratigraphic sequence of loess overlying till deposits are common along the major drainageways and their larger tributaries.

Drainage.

A system of internal drainageways characterized by relatively short, moderately branching tributaries, without junction with major streams is now found on the upland flats. The larger streams and rivers, the Skunk, Iowa, and Des Moines, have roughly parallel courses extending southeast to their junctions with the Mississippi. The tributary streams of the major rivers have a dendritic pattern and within their own length have only a slight meandering trend. The Iowa River exhibits a strong meandering trend northwest of the sample area and in the northwest portion of Louisa County. Below the junction of the Cedar River meandering has occurred in the past, as evidenced by sloughs and oxbow lakes. The floodplain of the Iowa River is far wider than those of the Skunk or Des Moines, approaching a width of at least four miles near Wapello in Louisa County. This differ-

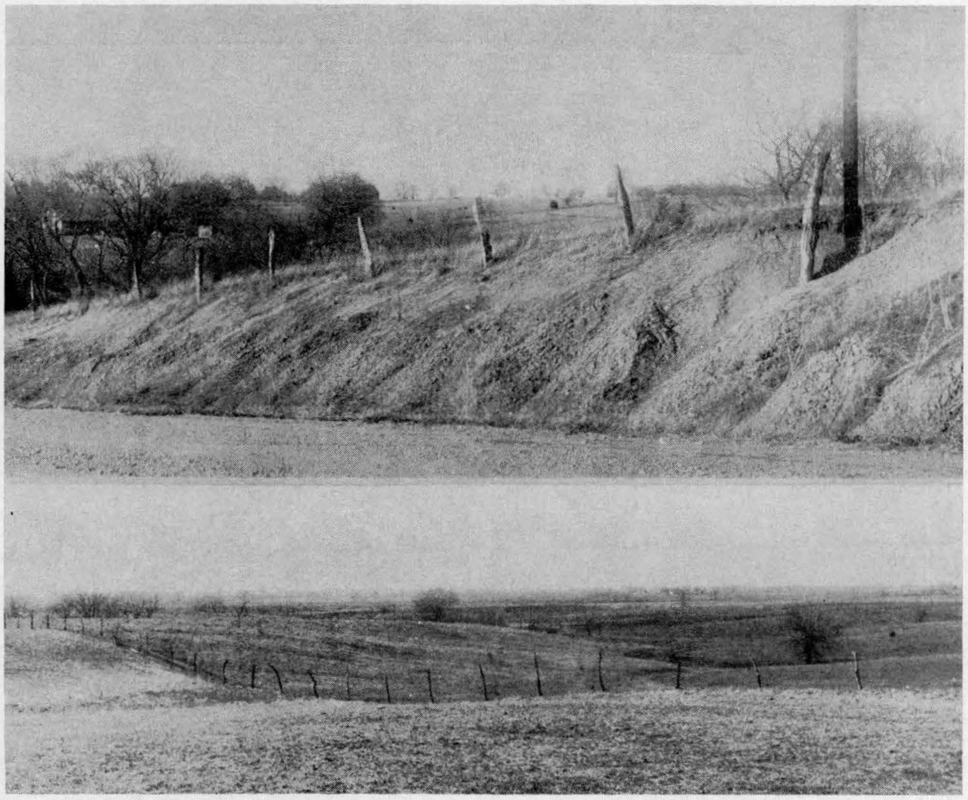


Fig. 5, above. Strongly dissected terrain at site of Sample No. 429-4. Below. Gently rolling loess covered slopes at edge of upland divide in Henry County.

ence in width of floodplain is perhaps due to the difference in age of the rivers. The Iowa River is Pre-Iowan, and the Skunk and Des Moines are Post-Iowan. Terrace deposits can be found along all three rivers.

METHODS OF SAMPLING

The general location of till samples was determined with as little bias as possible[26]. Once the general location had been selected, a thorough survey of the area was made to determine the specific sample site. Requisites were:
1. Lack of loess cover (exposed A horizon)

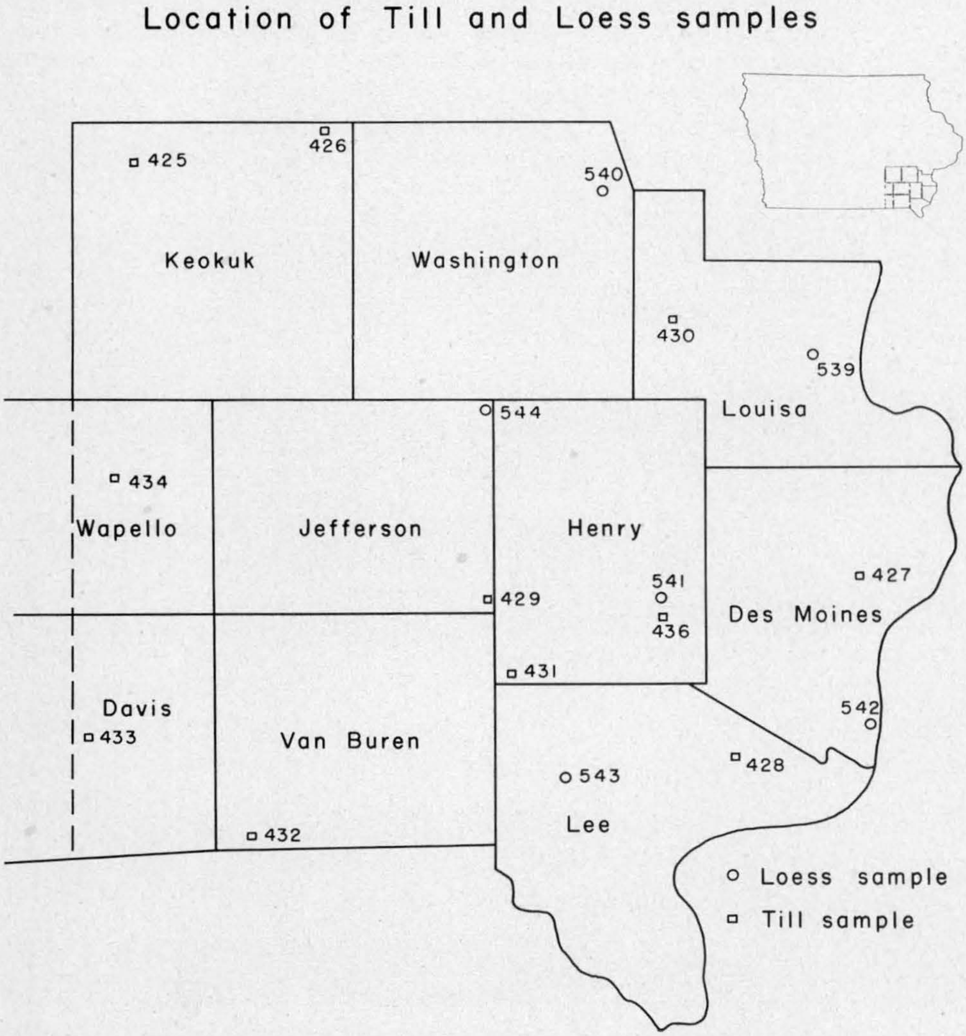


Fig. 6. Location of till and loess samples in southeastern Iowa area of investigation.

2. Completeness of section
3. Depth of section large as possible
4. Accessibility for bulk sampling

Loess sample sites were determined by a grid system which was extended eastward from the areas previously studied[7,26]. Completeness of section and accessibility for bulk sampling were the major considerations. Detailed samples were taken as close as possible to the grid intersections. All sites chosen for either loess or till samples were in road cuts.

TABLE II. DETAILED LOCATIONS OF TILL AND LOESS SAMPLES OBTAINED IN SOUTHEAST IOWA.

Sample No.	Section	Tier and Range	Township	County	Horizon designation and sampling depth		Soil Series
425-3,4	SW¼, SW¼, S-24	77N-13W	Prairie	Keokuk	C_1	23-87″	Shelby
425-5	" " "	" "		"	C_2	87-205″	"
426-5	NW¼, NW¼, S-4	77N-10W	Liberty	Keokuk	C_1	30-39″	Shelby
426-6	" " "	" "		"	C_2	39-97″	"
427-4	NE¼, NE¼, S-17	71N-1W	Benton	Des Moines	C_1	35-79″	Lindley
427-5	" " "	" "		"	C_2	79-108″	"
428-6	SE¼, SW¼, S-32	69N-4W	Denmark	Lee	C_1	42-67″	Lindley
429A-4	SE¼	71N-8W	Round Prairie	Jefferson	C_1	28-79″	Lindley
429A-5	"	" "		"	C_2	79-117″	"
430-4	NE¼, NW¼, S-33	75N-5W	Columbus	Louisa	C_1	22½-37″	Lindley
430-6	" " "	" "		"	C_2	53-82″	"
431-5,6	SW¼, SW¼, S-32	70N-7W	Salem	Henry	C_1	35-111″	Lindley
432-3	SE¼, SW¼, S-32	67N-11W	Jackson	Van Buren	C_1	17-62″	Lindley
432-4	" " "	" "		"	C_2	62-68″	"
433-5,6	NW¼, NW¼, S-31	69N-13W	Cleveland	Davis	C_1	22-96″	Lindley
433-7	" " "	" "		"	C_2	96-103″	"
434-4,5	SE¼, NW¼, S-4	72N-13W	Dahlonega	Wapello	C_1	29-79″	Lindley
435-2	S-7	71N-6W	Center	Henry	C_1	33-52″	Clinton
435-12	"	" "		"	C_2	190-195″	Lindley
436-4	NE¼, NE¼, S-34	71N-5W	New London	Henry	C_1	173-241″	Lindley
436-5	" " "	" "		"	C_2	241-348″	"
539-5	NW¼, NW¼, S-15	74N-3W	Port Louise	Louisa	C_1	71-101″	Clinton
540-5	SW¼, S-12	76N-6W	Highland	Washington	C_1	51-82″	Clinton
541A-4	SE¼, SW¼, S-22	71N-5W	New London	Henry	C_1	54-76″	Grundy
542A-5	NE¼, NW¼, S-17	69N-2W	Burlington	Des Moines	C_1	63-71″	Grundy
543-4	SE¼, SE¼, S-12	68N-7W	Harrison	Lee	C_1	34-72″	Grundy (or Putnam?)
544-4	SE¼, SE¼, S-2	73N-8W	Walnut	Jefferson	C_1	23-103″	Clinton

Field Methods. Individual horizons of the solum were determined as closely as possible by variations in color, content of organic material, structure, texture, and depth of root penetration.

The C horizon was subdivided on the basis of color and carbonate content. Non-calcareous loess and till are designated C_1, according to agronomic practice, and calcareous materials are designated as C_2.

At each location the surface was cut back approximately two feet to avoid contamination from materials which might have slumped from topographically higher positions.

In some locations, where road cuts were very shallow, a two inch auger was used to obtain deeper samples. Samples were numbered according to an established system. The 400 series represent till samples with the exception of 435-2, which is loess overlying a till sequence. Numbers in the 500 series represent loess samples. Occasionally it became necessary to resample a section due to loss or contamination of the original materials. Those marked with an "A" following the series number have been resampled at the original location. Samples marked "AS" represent auger samples (figure 6 and table II).

ANALYSIS OF LOESS AND TILL

Mechanical Analysis.

Mechanical analyses of both till and loess samples were by modified sieving and hydometer methods[6]. Sodium metaphosphate was used as the dispersing agent to avoid flocculation of the clay fraction. Following the hydrometer analysis the sample was wet sieved through a No. 200 sieve (74 micron). Coarse materials retained on this sieve were oven dried at 105°C for 24 hours, then were placed in a nest of No. 20, No. 40, No. 60, No. 140, and No. 200 sieves. The nest was mechanically shaken for five minutes. After the materials retained on each sieve were weighed the percent by weight of each size fraction was calculated, and the results were graphically plotted on 4 cycle log paper. The size classifications are in accord with A.A.S.H.O. designations.

Engineering Tests for Soil Properties.

Atterberg tests were made on each sample to determine the engineering properties of the soil. These consistency and classification tests include:

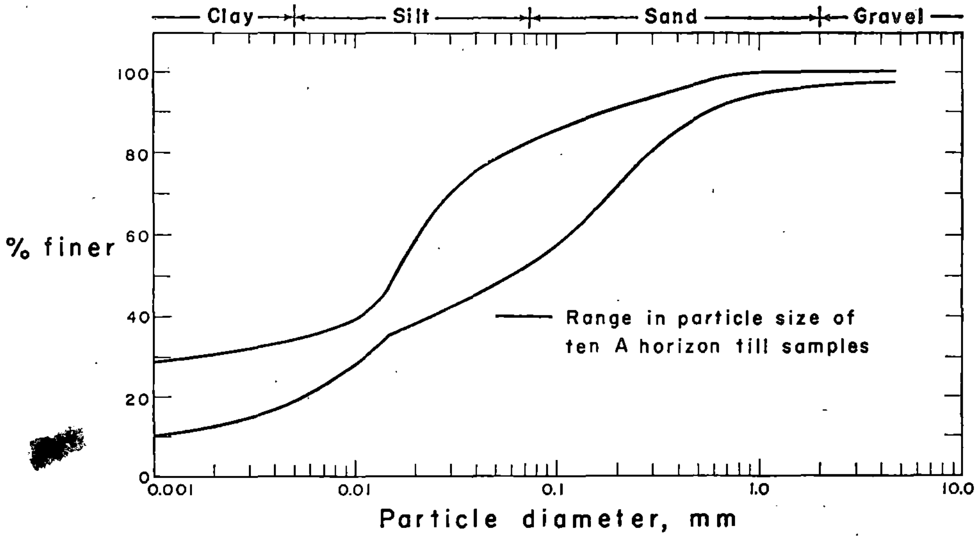
1. Liquid limit (A.S.T.M. Designation: D423-54T)[2]
2. Plastic limit (A.S.T.M. Designation: D424-54T)[2]
3. Plasticity index (A.S.T.M. Designation: D424-54T)[2]
4. Engineering classification (A.A.S.H.O. Designation: M145-49)[1]

Differential Thermal Analysis.

The C horizon study samples were analyzed with a differential thermal analysis apparatus[14, 20]. Samples in both the minus 44 and minus 5 micron size fractions were kept in an atmosphere of 50-55 percent relative humidity for about two weeks prior to analysis.

Petrographic Analysis.

Separation into size fractions—Whole samples representing each of the materials selected for detailed study were separated into size fractions by air dispersion, elutriation and sieving. Sodium metaphosphate was used as a dispersion agent in both the air dispersion and elutriation methods[14].



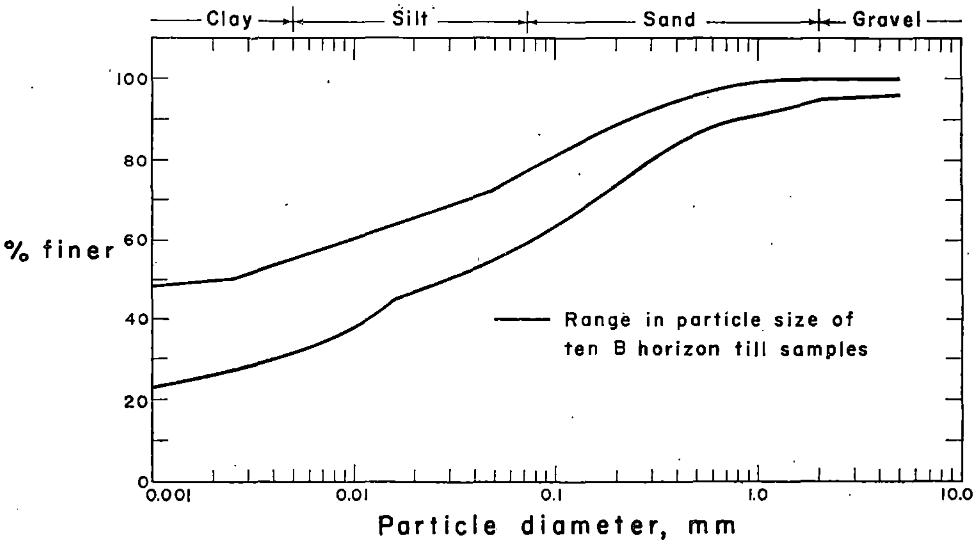
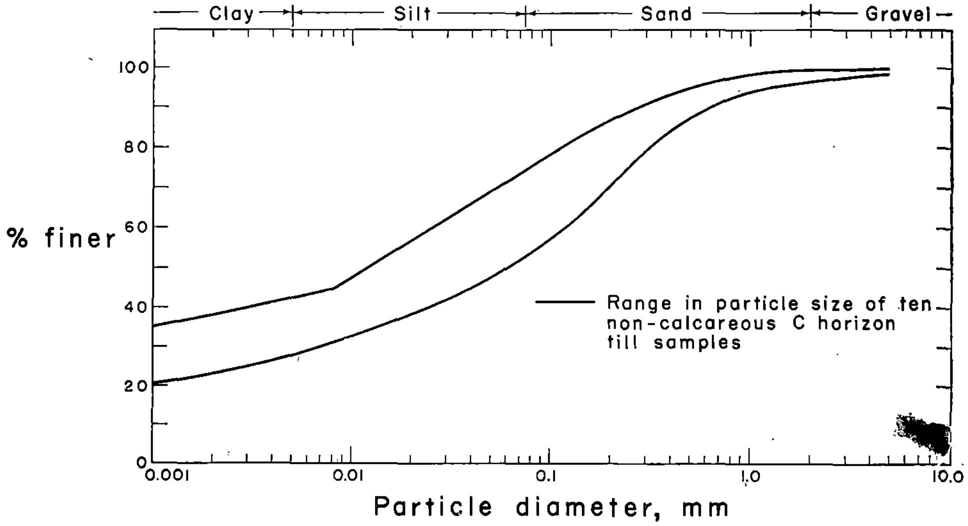


Fig. 7. Particle-size distribution curves of several A and B horizon till samples.

Mounting—The 20-44 micron size fraction, chosen to represent most nearly the median diameter of all samples, was permanently mounted in Lakeside cement. This particular cement is excellent, since it handles both light and heavy mineral fractions without need for bromoform separation, and its index of refraction (1.534 to 1.540) is similar to balsam.

Mineral determinations—Mineral determinations were made with a Leitz petrographic microscope utilizing an 8x ocular and 100x oil immersion ob-



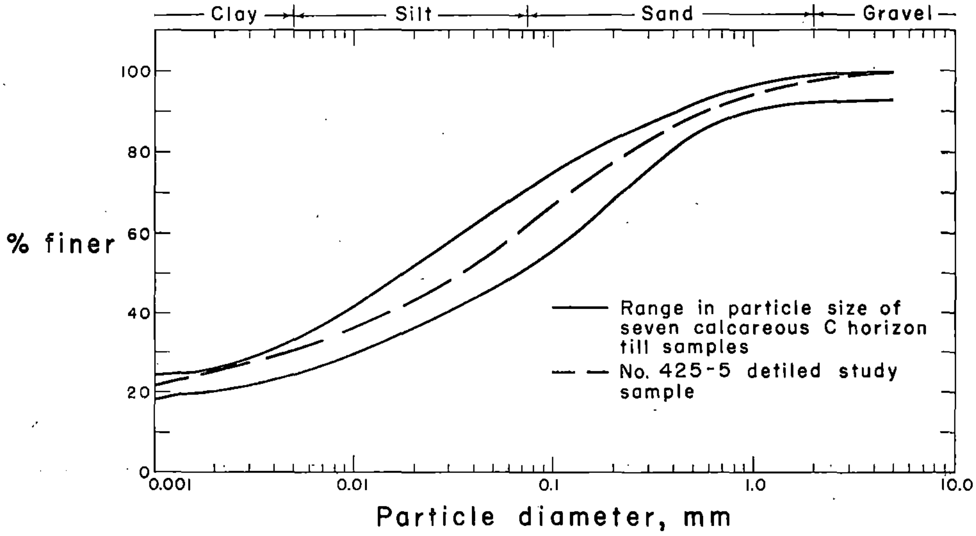


Fig. 7, cont'd. Particle-size distribution curves of several C horizon till samples.

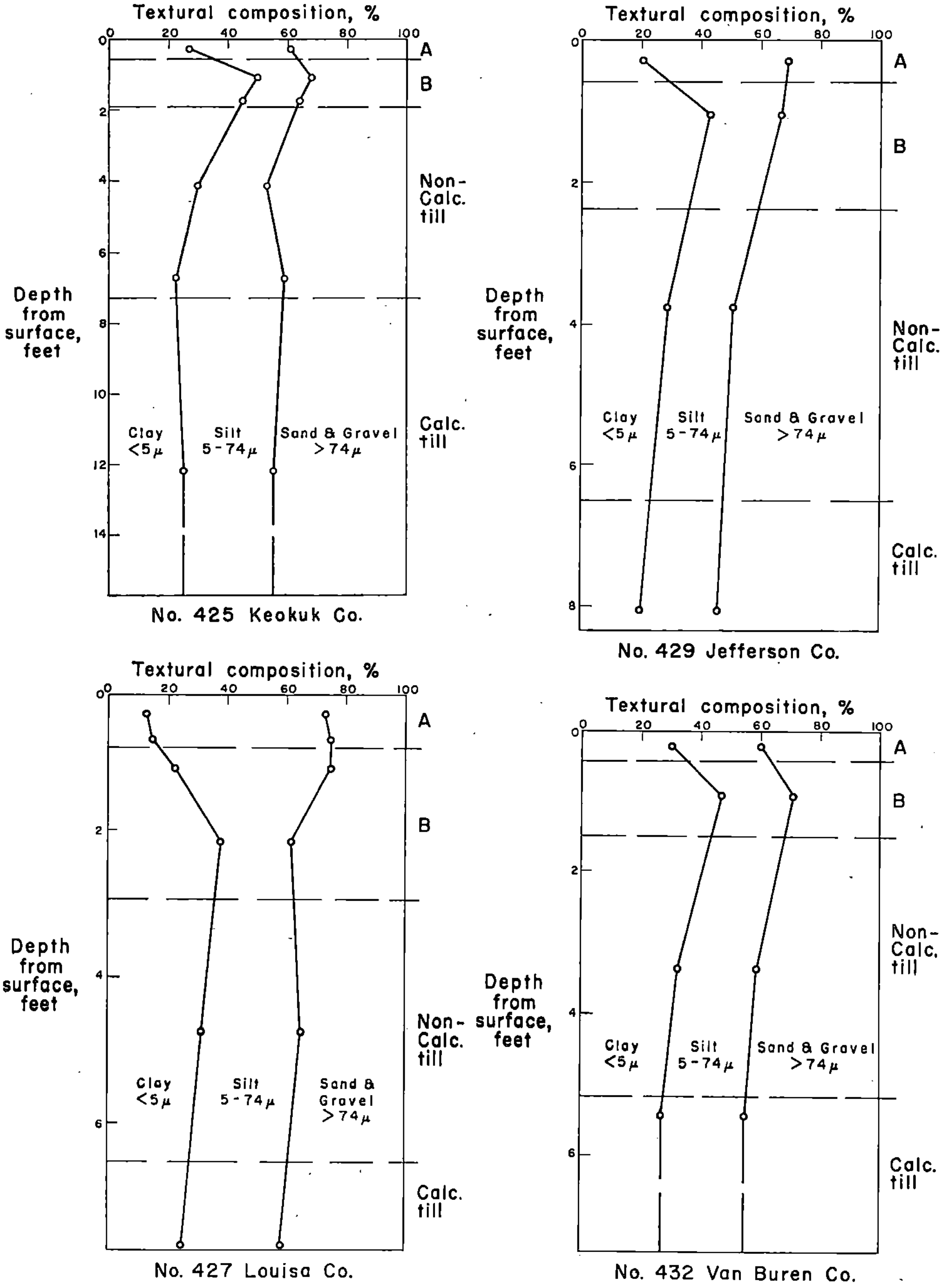


Fig. 8. Textural variation with depth of several Kansan till profiles.

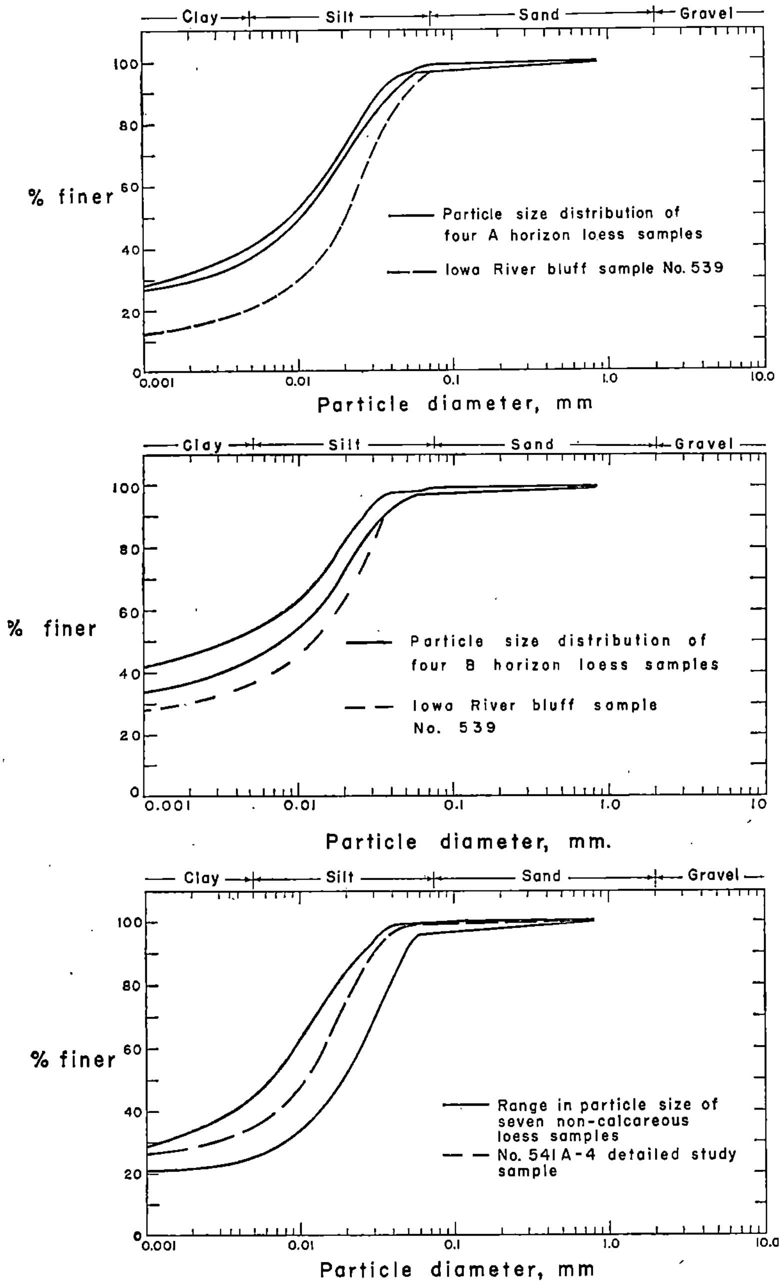


Fig. 9. Particle-size distribution curves of several A, B, and C horizon loess samples.

jective lens. Over 200 grains were counted for each sample. These grain counts were converted to percent of whole sample.

Opaque minerals were identified on the basis of shape, color, and appearance in low angle incident light.

Particle-Size Analysis.

Glacial till. Particle-size distribution curves are given for all A, B, non-calcareous and calcareous till horizons (figure7). The A horizons sampled include those of composite origin, therefore their range in texture is greatest. The range in particle-size distribution of the B horizons is somewhat more confined than for the A horizons, but is spread in the clay and fine silt fractions by a few samples of composite origin (figure 8).

Curves of the C horizon samples are very similar, though they shift slightly due to variations in the different size fractions. The finer textured samples are higher in the silt and clay fractions than the coarser textured samples. A comparison of the non-calcareous and calcareous tills shows that in general the variation in clay content is greater between all non-calcareous tills than between calcareous samples. Again, the overall clay content is usually higher in non-calcareous horizons than in calcareous ones.

Excluding those horizons of composite origin, the samples show a distinct trend in the content of clay-size material. The A horizons usually show less clay than the B. The profiles graphically illustrate the sharp increase in clay content from the A to the B horizon and the more gradual

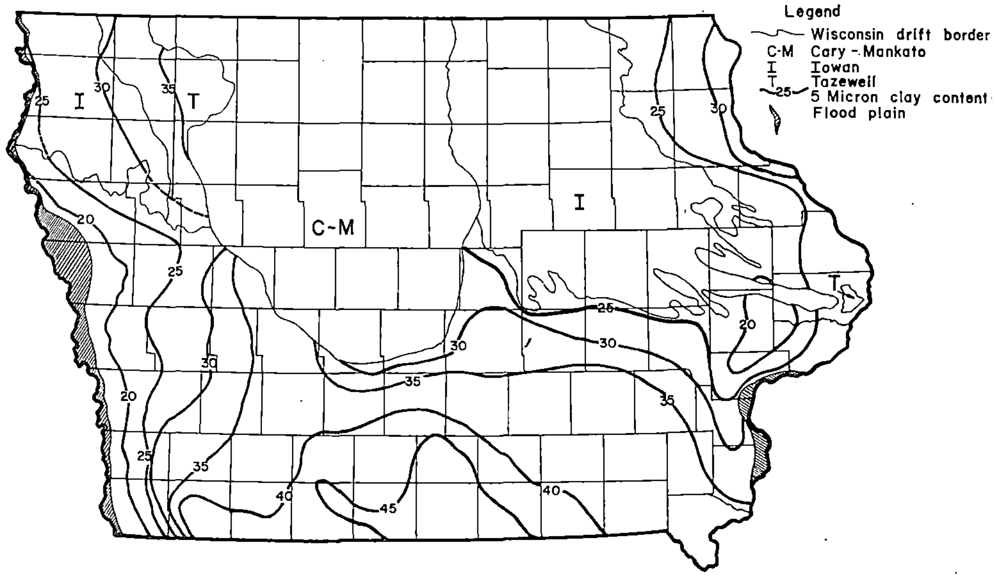


Fig. 10. Trends in clay content of Wisconsin loess.

decrease with depth into the C horizon. In the C horizon clay, silt, and sand are about equal in abundance, but the gravel fraction rarely exceeds six percent.

Loess.

The range in particle-size distribution for the A, B, and C horizons of the loess show the same trend in clay content as that for the till sections, that is, the A contains less clay than either the B or C horizons (figure 9).

Clay content decreases to the north and northeast, with a corresponding increase in the silt fraction. The sand content remains quite uniform, varying less than one percent except in those samples near the bluffs bordering major floodplains (figure 10).

Quartile measures may be obtained and can be used to determine approximately the conditions in the transporting medium at the time of deposition (figures 8, 9).

The second quartile (50 percent value) determines the median diameter of the sediment. The sorting coefficient gives an indication of the extent to which all grains depart from the median size[33]. The coefficient So, is expressed as the square root of the ratio of the third quartile to the first quartile. Since a sorting coefficient of one (1) indicates no deviation from the median, all particles must therefore be of the same size. This would indicate excellent sorting, due to a sharp change in the velocity of the transporting medium. Values above one indicate the more normal variations expected in wind transported materials, glacial outwash streams, or in the water saturated heterogeneous mass transported by the glacier itself.

The values obtained for the median diameters of non-calcareous till, calcareous till, and loess indicate that they all fall into the silt size fraction. Those of the tills range from fine to coarse silt, and those of loess from very fine to fine silt.

A well sorted sediment has a sorting coefficient of less than 2.5.[33] Using this value as a reference, the tills are very poorly sorted, and the loess is poorly sorted.

A well sorted sample is poorly graded with little variation in particle size. The effective size and uniformity coefficient can be used to determine the general grading of a sediment[32]. The effective size is the maximum diameter of the smallest 10 percent, by weight of the soil particles. Uniformity coefficient is the quotient obtained by dividing the maximum diameter of the smallest 60 percent by weight of the soil particles by the effective size.

A low value of the effective size indicates that the sediment has a relatively large amount of fine material, and a high value indicates a relatively smaller percentage of fines. A uniformity coefficient value of 1 indicates that all particles are the same size, and a value of 300 indicates a well graded sediment. The effective size of all four detailed study samples could not be obtained with any accuracy even by interpolation. For this reason no uniformity coefficient is shown, but a very rough estimate of the uniformity coefficient for the till soils is about 285, thus placing them in the well graded range (table III).

Engineering Analysis.

Physical tests. Analysis of all loess and till samples were performed to determine their physical properties (table IV).

The plasticity index of a soil represents the range of moisture content within which the soil exhibits the properties of a plastic solid. It is defined as the numerical difference between the liquid limit and the plastic limit of the soil[32]:

(Plasticity index=Liquid limit—Plastic limit.)

The plasticity index is also an empirical indicator of the suitability of the clay fraction of a binder material in a stabilized soil aggregate mixture (1, A.A.S.H.O. Designation: M147-49). Too high a plasticity index indicates the possibility of softening when wetted, and too low an index strongly indicates the possibility of severe abrasion when dry.

Engineering classifications of soils are based on the plasticity index and the textural composition. Under the classification standardized by the A.A.S.H.O., both the Kansan and Illinoian till samples fall into the A-6

TABLE III. TEXTURAL COMPOSITION AND GRADING VALUES FOR FOUR DETAILED STUDY SAMPLES.

Property	Sample Number			
	425-5 Kansan till	429-4 Kansan till	436-5 Ill. till	541A-4 Loess
Gravel, % greater than 2.0 mm.	2.5	1.5	4.3	0.0
Sand, % 2.0 to 0.42 mm.	10.5	13.5	5.7	0.2
Sand, % 0.42 to 0.074 mm.	25.1	34.5	19.0	0.8
Silt, % 0.074 to 0.005 mm.	30.9	24.5	38.0	63.5
Clay, % less than 0.005 mm.	31.0	26.0	33.0	35.5
Median diameter, mm.	0.034	0.066	0.017	0.011
First quartile, mm.	0.0020	0.0044	0.0010	0.0010*
Third quartile, mm.	0.17	0.26	0.10	0.021
Sorting coefficient, So	9.22	7.68	10.	4.58
Effective size, mm.	†	------	------	------
Uniformity coefficient	‡	------	------	------

* Estimated
† Unobtainable
‡ Depends upon effective size

TABLE IV. ATTERBERG LIMITS, TEXTURAL, AND ENGINEERING CLASSIFICATIONS OF THE DETAILED STUDY SAMPLES

Property	Sample Number			
	425-5 Kansan till	429-4 Kansan till	436-5 Ill. till	541A-4 Loess
Clay content, %	31.0	26.0	33.0	35.5
Liquid limit	29.0	27.6	36.2	45.7
Plastic limit	17.0	14.7	15.3	21.1
Plasticity index	12.0	12.9	20.9	24.6
B.P.R. textural classification	Clay	Clay loam	Clay	Silty clay
Engineering classification	A-6(5)	A-6(6)	A-6(11)	A-7-(15)

classification. This category at once indicates that they are silty to silty-clay-like soils, with only a fair to poor rating as subgrade material. The loess sample No. 541A-4 is classed as an A-7 soil, indicating a more clay-like soil than the tills. The clay content is in fact only slightly higher than some of the tills, but the overall content of fines passing the No. 200 sieve is 99%

Differential Thermal Analysis.

Differential thermal curves for the four minus 5 micron fractions and one minus 44 micron fraction of the detailed samples show the endothermic reactions by the upward flexure (figure 11). With minor exceptions all curves are quite similar[20].

The most prominent endothermic peak, between 100 and 200°C, is attributed to the loss of absorbed water on the clay particles. The size of this initial peak suggests the presence of the montmorillonoid group. The small exothermic reaction at about 300°C may be caused by oxidation of organic matter.

The dual endothermic reactions characteristic of illite and montmorillonite are well shown in Sample No. 429-4. These reactions are commonly between 500 and 600° C and are attributed to the loss of OH^- water between the structural layers.

Quartz inversion is indicated in the minus 44 micron sample by the small sharp endothermic reaction at approximately 575°C. Carbonate is also indi-

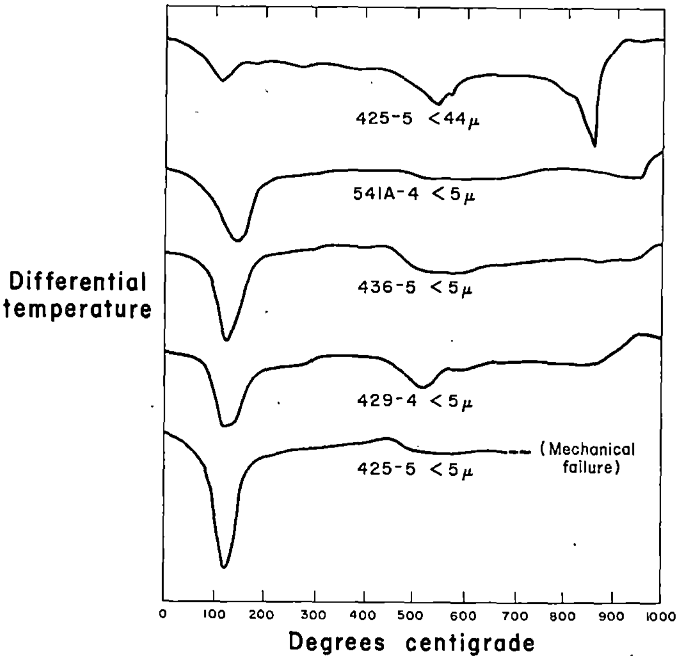


Fig. 11. Differential thermal analysis curves for four detailed study samples.

cated in this sample by the large, sharp endothermic flexure at 860°C. The exothermic reactions just above 900°C are attributed to the breakdown of the lattice structure and are followed by a slight endothermic reaction near 1000°C, which represents recrystallization of the materials:

The dominant clay minerals indicated by all curves appear to be montmorillonite and illite. Quartz apparently is not present in sufficient quantities to register in the minus 5 micron samples, although subsequent X-ray tests conclusively prove its presence. The indication of organic material is surprising, since the samples were all obtained below the depth to which this material presumably penetrates.

Mineral Studies

Results of four detailed mineral studies show that quartz and feldspar are the dominant minerals in all samples (table V). Carbonate is the third dominant mineral in all except the non-calcareous loess sample. Miscellaneous light minerals include all those expected to float in bromoform (sp. gr. 2.87) except quartz, feldspar, and carbonate. Miscellaneous heavy minerals include all those expected to sink in bromoform except iron concretions. Dominant heavy minerals are amphiboles and pyroxenes, with minor amounts of garnet, rutile, and magnetite. Minerals classed as altered and unidentifiable are probably feldspars although the high degree of alteration affords doubtful certainty of identification.

Several quartz grains in each sample are discontinuously coated with clay particles. These particles appear as minute greenish circles on the surface of the grain but cannot be resolved due to limitations in the optical system. Other quartz grains show inclusions of rutile and tourmaline; however inclusions were not counted separately. The variable nature of the quartz/feldspar ratio and the age of the parent material even between two samples of the same age, has prevented any conclusive results.

X-ray Analysis.

Minerals of less than 44 micron size range in the samples selected for detailed analysis were identified by X-ray diffraction. The diffractometer was a General Electric Model XRD-5 with a copper target tube. Radiation

TABLE V. MINERAL COMPOSITION, % OF 20-44 MICRON SIZE FRACTION

Mineral	Sample Number			
	425-5 Kansan till	429-4 Kansan till	436-5 Illinoian till	541A-4 Loess
Quartz	47	53	47	62
Total feldspar	25	24	19	20
Carbonates	17	7	18	1
Miscellaneous light	3	4	6	4
Miscellaneous heavy	4	5	5	8
Iron oxide concretions	2	4	2	2
Altered and unidentifiable	2	3	3	2
Quartz/feldspar ratio (not percent)	1.9/1	2.2/1	2.5/1	3.1/1

was monochromatized with a 0.089 mm thick nickel filter. A 1° beam slit, medium resolution Soller slits, and a 0.2° detector slit were used. The samples were scanned at 2°/minute, and recorded on a strip chart moving at the rate of one inch per minute. From the above data the setting of the time constant (RC) in the pulse averaging circuit to obtain maximum resolution was determined to be 3 seconds.

$$\text{RC maximum} = \frac{W}{2}$$

$$W = 60 \text{ x } \frac{v}{w} \text{seconds}$$

Where

W = time width of the detector slit
v = angular width of the slit
and w = scanning velocity in degrees/minute

Identification of the mineral components was initiated by converting the peak locations in degrees to interplanar (d) spacings expressed in Angströms. From the values obtained, identification was made by A.S.T.M. diffraction data cards[5].

The X-ray diffraction studies presented in this report were intended primarily to supplement the petrographic analysis, particularly of the clay minerals in the minus five micron size fraction.

The process of elutriation, in which this minus five micron fraction is obtained, also results in the separation of the silt and fine sand fraction of the dispersed whole sample.

Additional data concerning these fractions are therefore presented, both to serve as checks on the results of prior analyses and to yield information which may be of aid in future soil stabilization projects.

X-ray diffraction traces (figures 12, 13, 14 and 15) are for several size fractions of Kansan glacial till (No. 425-5), (No. 429-4 check sample), Nebraskan till (No. 436-5), and Wisconsin loess (No. 541A-4) respectively. All samples including the undispersed whole sample (minus 44 micron) were run dry and also with glycol treatment[6].

Prominent reflections in figure 12 at 17.66 Angströms in the less than 44 micron fraction are interpreted as the first order basal spacing for glycolated montmorillonite. First order basal spacings for illite and kaolinite are also suggested by the moderate reflections at 10.04 and 7.07 Angströms respectively.

Dry mounting of the minus 5 micron materials revealed a broad irregular band in the 10 to 18 Angström range, moderate illite and kaolinite spacings, and distinct though relatively weak quartz reflections at spacings of 4.25, 3.35, and 2.46 Angströms.

Glycol treatment shifts the 10 to 18 Angström band, causing it to intensify at 17.66 Angströms, thus definitely indicating the presence of montmorillonite. Illite and kaolinite peaks are strongly defined, but the peak height of quartz is relatively unaffected.

There is no evidence of montmorillonite, and the presence of chlorite-vermiculite is extremely doubtful in fractions above 5 micron size. The first prominent reflections occur at 10.04 Angströms and indicate the first order reflection of illite. Illite also shows spacings at 4.95 to 4.97, and 2.53 to 2.56 Angströms. Reflections which occur at 3.18 to 3.21 also indicate illite.

Kaolinite shows strong diagnostic spacings at 7.13 to 7.19 and 3.57 Angströms. Chlorite could also be possible with this spacing, but the absence of any 14.24 Angström reflections in the 5 micron sample makes this a doubtful possibility.

Quartz reflections at 4.25 to 4.27, 3.35, and 2.45 Angströms are in increasing intensity in all successively larger fractions.

The carbonates, both calcite and dolomite, are evidenced by reflections at 3.03 and 2.88 Angströms respectively. Though at first only minor constituents in the finer fractions, these minerals increase in intensity and presumably in quantity through the 44 to 74 micron range, then appear to decrease slightly.

Materials larger than 74 microns were obtained by wet sieving the un-

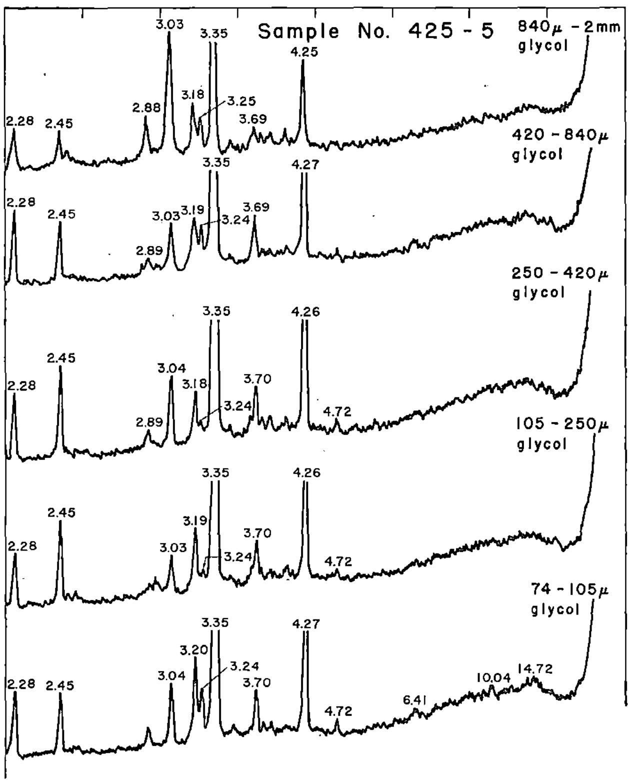


Fig. 12. X-ray diffraction curves for several size fractions of Kansan till Sample No. 425-5.

dispersed whole sample through a nest of sieves. Fractions ranging in size from 74 to 420 micron were ground for one hour in a mechanical mortar and pestle whose components, constructed of Mullit, virtually eliminate any trace of contamination. Materials larger than 420 microns were first ground

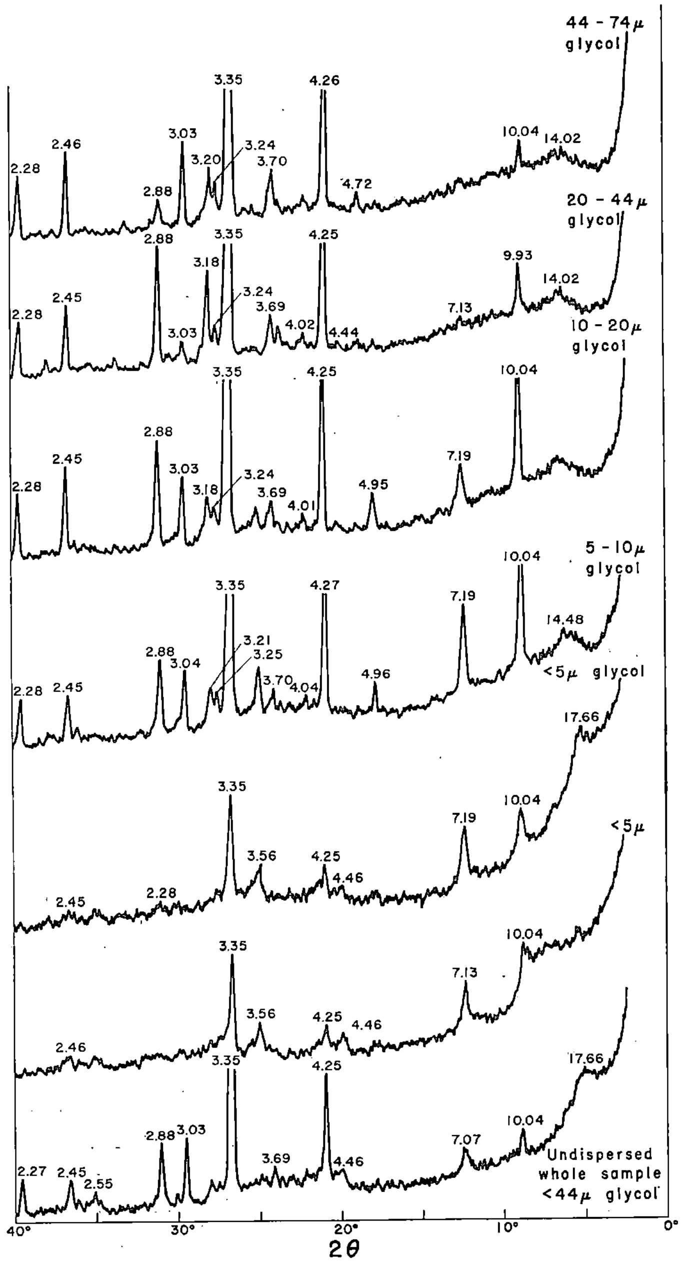


Fig. 12, cont'd. X-ray diffraction curves for several size fractions of Kansan till Sample No. 425-5.

for one hour in a one quart ball mill with flint pebbles as the grinding media. Following the grinding period the resulting fine powder was transferred to the mechanical mortar and pestle for reduction to less than 44 micron size.

Quartz, feldspar, the carbonate, and traces of muscovite-biotite are the only recognizable minerals in the large size fractions, with quartz and feldspar dominant.

A strong reflection at 3.70 Angströms, more intense than normal for feldspar and more prominent in larger fractions, remained an enigma for some time until a co-worker discovered that quartz CuK β radiation was being passed by the nickel filter. Doubling the filter thickness effectively removed or reduced the peak, though it reduced other reflections. For this reason a single thickness of nickel filter was again used for the remaining tests.

Quartz and feldspar, minor constituents in the smaller size fractions, showed a trend of increasing quantity as the size of each fraction increases. The carbonates, apparently absent in the minus 5 micron fraction, increase in quantity through the 44 to 74 micron size, then decrease. Illite, kaolinite, and montmorillonite are the clay minerals in this sample. The chlorite-vermiculite complex was not substantiated.

Size fractions of a check sample with several traces of a glycolated Kansan till were obtained by the methods previously described for Sample No. 425-5 (figure 13). In this sample the first good indications of the chlorite-vermiculite complex are found as part of the broad band ranging from 11 to 16 Angströms. Initially, a procedure was used to differentiate the complex[5]. Heating to 700°C should not destroy a 14 Angström chlorite reflection, but it caused the replacement of the normal 14 Angström vermiculite spacing by one at 9 to 9.3 Angströms, which represents the basic talc structure. This method was followed by heating the sample for one half hour in a constant temperature furnace before resuming standard diffraction procedure. The trace for this sample clearly indicates the removal of the 14 Angströms reflection and the consequent replacement of a distinct though weak reflection at about 8.5 to 9 Angströms. Vermiculite is thus distinguished. This test also proves kaolinite rather than chlorite by the 7.13 Angström reflection since the kaolinite structure is destroyed[13] at this temperature, but chlorite would be unaffected.

Prominent 14.72 Angström reflections are in the 5 to 10 micron fraction. A second test for vermiculite was conducted with this fraction by a method which makes vermiculite lose its normal spacing when gently boiled with an ammonium salt for 5 minutes[5]. The newly formed spacing then occurs at approximately 11 kx (1 kx = 1.00202 Angströms). Results of this test were most satisfactory; and although the trace is not known, a moderate reflection was obtained at about 10.5 Angströms.

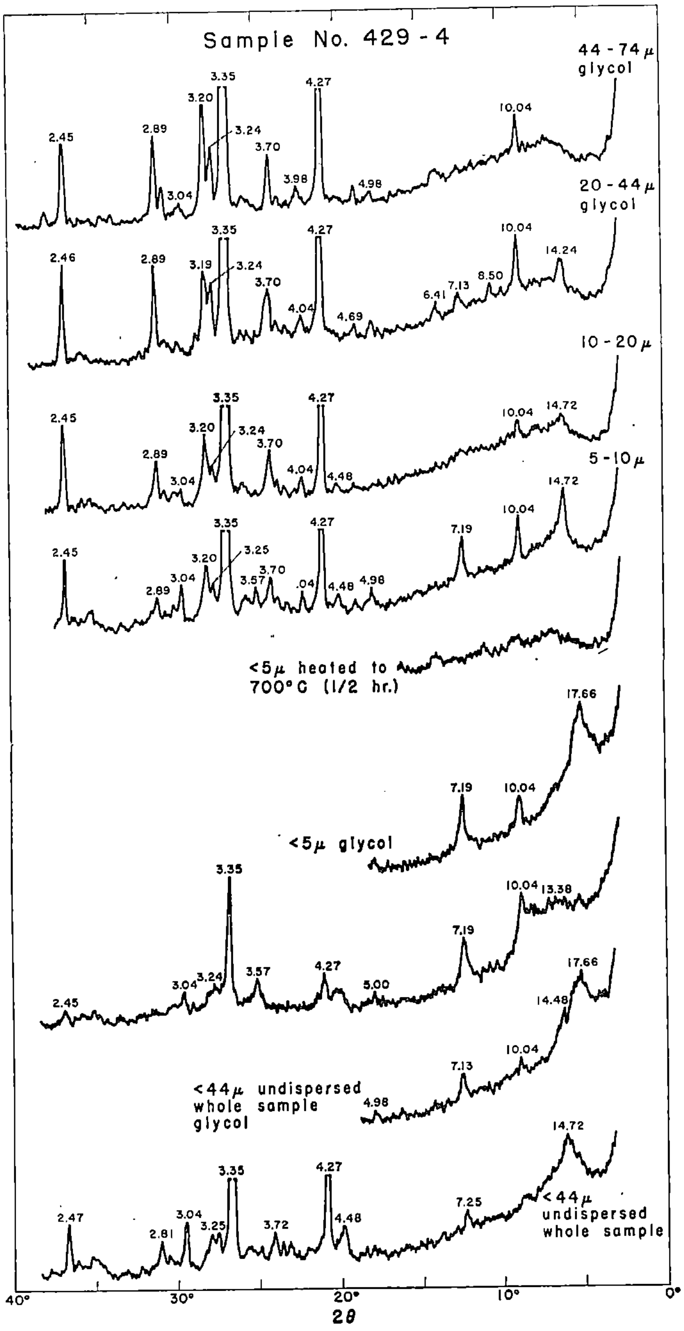


Fig. 13. X-ray diffraction curves for several size fractions of Kansan till check Sample No. 429-4.

Glycol treatment of both the minus 44 micron and minus 5 micron samples produces strong diagnostic montmorillonite reflections at 17.66 Angströms. Illite basal spacings yield reflections at 10.04 and 4.98-5.0 Angströms. The very strong 7.19 and 3.57 reflections are diagnostic of kaolinite. These reflections are present in reduced intensity through the 20 to 44 micron size fraction, and as such they may represent adherence of the mineral as thin surficial coatings to the larger grains.

Characteristic reflections at 4.27, 3.35, and 2.45 Angströms indicate quartz in all sub-samples.

The analysis of this sample shows clay minerals in the minus 5 and 5 to 10 micron fractions in relative abundance. The amount decreases as expected in the larger particle-size assemblages and except for surface coatings on certain particles should be absent in the 20 to 44 micron fraction.

The vermiculite in this sample cannot be satisfactorily explained at this time. Since No. 425-5 and No. 429-4 are both samples of the C_2 horizon

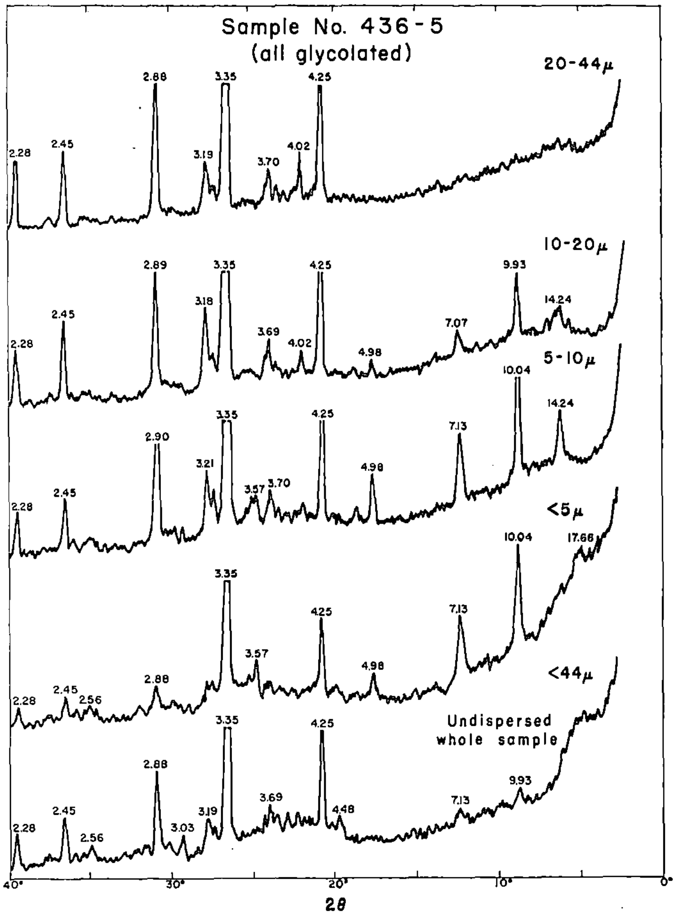


Fig. 14. X-ray diffraction curves for several size fractions of Illinoian till Sample No. 436-5.

of Kansan till, their mineral assemblages should be similar. It is possible that certain soil forming factors or weathering phenomena play a more important role than presently realized.

The first reflection at 17.66 Angströms for glycolated traces of several fractions of Illinoian till (No. 436-5) is characteristic of montmorillonite. This spacing is rather broad and diffuse in the undispersed whole sample trace, but it clarifies somewhat in the minus 5 micron sample. Illite and kaolinite are represented by the intense peaks at 10.04 and 7.13 Angströms respectively. Second order illite spacings are clearly defined in the 5 to 20 micron fractions at 4.98 Angströms (figure 14).

Quartz causes large, characteristic reflections at 4.25, 3.35, 2.45 and 2.28 Angströms. Feldspars are indicated by the reflections at 3.70 and by those between 3.2 and 3.3 Angströms, although some portion of the 3.70 peak is undoubtedly due to unfiltered quartz copper K radiations.

The unnatural height of the 2.88 Angström peak leads to the speculation

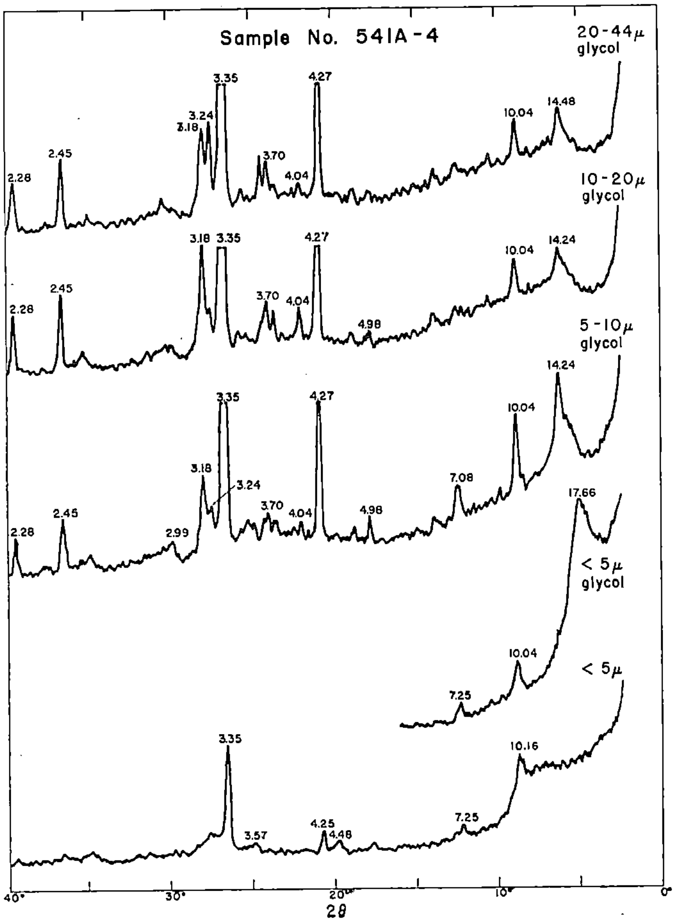


Fig. 15. X-ray diffraction curves for several size fractions of loess Sample No. 541A-4.

that dolomite is not the only contributing mineral. To date, however, no alternative choice is indicated by the remaining peaks.

Stratigraphically different tills vary not in broad mineralogical aspects but in relations of mineral quantities (figure 14). It was hoped that this sample might produce significant data which would serve as a basis of differentiation, but the apparent result is that tills may be differentiated only by field analysis.

An extremely strong 17.66 Angström peak in the minus 5 micron fraction occurs at the location characteristic of glycolated montmorillonite first order basal spacings (figure 15). The glycolated traces represent diffraction studies of a non-calcareous loess. The more diffuse band which extends from 2 to 6 degrees in the non-glycolated sample again suggests a relatively high clay content, since its position is significantly higher (stronger) than the remainder of the trace. Illite and kaolinite give moderate reflections at 10.16 to 10.94, 7.25 and 7.08 Angströms.

Size fractions greater than 5 micron show a strong 14.24 Angström reflection. To determine whether chlorite or vermiculite was the suspected mineral the sample was heated to 700°C for a half hour. The peak at 14 Angströms was destroyed, leaving only a weak reflection at approximately 9 Angströms, suggesting vermiculite and perhaps some hydrous mica.

Quartz is indicated by the well defined reflections at 4.27, 3.35, 2.45 and 2.28 Angströms. Feldspars are reflected between 3.1 and 3.2 Angströms. No reflections at 3.04 Angströms, indicative of calcite, are in any of the several size fractions. This of course is to be expected in a non-calcareous sample.

DISCUSSION

Upland Surfaces.

Loess is primarily on the upland surfaces and on gently sloping shoulders. The average thickness throughout the area in an east-west direction is approximately ten feet. From this broad band, thickness decreases to the south and increases rapidly to the north. A slight thickening trend to the east has been noted in east-west traverses which approach the Iowa and Mississippi rivers. These somewhat thicker deposits are bluff-like in nature and have slightly higher contents of fine sand.

Loess in western Iowa seems to be primarily a product of eolian transportation[26]. The widespread nature of the deposit, coupled with the fact that loess apparently blankets erosion surfaces and divides without regard to previous topographic relief appear to have been the major points leading to this conclusion.

Loess deposits in Wapello and Davis counties may represent the maximum distance in transportation from the source on the Missouri River floodplain. Reasoning thus, it may be that coarser materials have been deposited in the western counties, while the finer more clay-like materials were concentrated in the east. The surface which now underlies the area of the Cary-Mankato drift is an important source of loess. Slightly more coarse textured loess as found in the eastern portion of the area of study may represent partial sorting of material transported from this pre-till surface.

The upland surfaces are rather poorly drained, both externally and internally. Several borings in the loess show the water table at a depth between six and seven feet. Above the water table the loess is moist but still easily workable. Below the water table however, the loess is saturated and sticky.

At the level of the water table or slightly above it, bright orange bands a few inches thick roughly parallel the surface topography. These bands contain iron oxide concretions which alter the textural composition. Their origin may have been due to an upwards migration of ferrous iron which was oxidized in the oxygen rich zone above the water table.

Clay content in loess varies inversely with thickness. Samples obtained from Wapello and Davis counties where the loess thickness averages five feet show higher clay contents than those samples obtained further north and east in the ten foot band. Clay content seems to be a function of topography, internal drainage, and distance to site of deposition from source area. Weathering time, or age of parent material, is also important in clay formation.

Poor internal drainage favors the formation and accumulation of clay. Clay is transported downward by the action of percolating groundwater and concentrates in the B horizon. When the internal drainage is better, as on sloping terrain, the clay may be carried away before it reaches a favorable accumulation site. Layers of sandy-silt are below the loess regardless of topographic position.

Rolling Topography

Till underlies the loess both on the uplands and on the shoulders of the divides. The thinning nature of the loess and the more advanced state of dissection contribute to the widespread exposure of the till on the rolling terrain. In fact, no till was observed to outcrop on any portion of the upland surface.

Profile development of the solum is generally less well developed on the rolling topography than on the upland surfaces, since erosion removes many of the weathering products as they are formed. Gumbotil outcrops on the sloping shoulders just below the upland surface, but its formation has occurred under past rather than modern soil forming conditions.

The sandy silt layer exposed at many places shows greater stratigraphic thickness than on the uplands. Theories concerning the origin of this layer are that slope-wash is the dominant factor of formation[7]. The widest variations of the solum are therefore found in this dissected terrain. Loess, till, and sandy silt are the most frequent, but significant deposits of alluvial and colluvial nature must also be dealt with in engineering applications.

Engineering Considerations.

Relief on the upland surfaces is seldom greater than ten feet, hence preparatory grading for highway construction usually does not expose other soils than those developed from the loess parent material.

Loess is however, by definition, a predominantly silty material, relatively high in clay. The engineering advantage of dealing with one parent material is offset somewhat by the sensitivity of the loess to changes in moisture content. The high silt content is of importance in the generally high porosity attributed to this material. Permeability, also considered to be relatively high, varies inversely with clay content. Moisture variations even in a properly constructed base course can reduce the load bearing capabilities by decreasing the density. Loess is also susceptible to frost heaving, due to the high capillarity of the silt sized particles. Swelling of the montmorillonite clays and hydrous micas over a period of time may produce detrimental plastic flow in the base course.

Rolling topography presents a more varied sequence of soil materials. Not only is there loess, but all manner of till derived soils including gumbotil as well as sandy silts, colluvial and alluvial soils. Construction projects conducted within this terrain can therefore be expected to traverse any number of these soil materials.

Of all these materials, glacial till seems best suited for the construction of base courses. It is usually well graded, therefore compacted densities, which seldom exceed 105 to 110 lbs/cu. ft. with loess soils, can be increased to 120 to 130 lbs./cu. ft. in till soils.

Stabilization of some soils to increase their suitability for highway usage presents additional problems. Gumbotil is difficult to stabilize, and due to the high clay content it is hard to mix properly and requires excessive amounts of stabilizing agents. Permanent mechanical stabilization is rarely achieved since the unusually high water absorbing capacity prevents a high compacted density.

The sandy-silt should be a good base course material, and could be mechanically stabilized by compaction if it had a relatively high coarse sand content. If the sand fraction were predominantly of fines, chemical stabilizers probably would be required. Sandy-silt however overlies the gumbotil or high clay B horizons of the till, and these materials would also have to be stabilized for lasting results.

SUMMARY

The loess in southeastern Iowa is a widespread deposit which blankets the terrain. It has been removed by the process of erosion from steeply rolling landscapes and from alluvial floodplains. Actually it is doubtful if any deposits of significance ever formed on these floodplains, since removal and deposition were probably simultaneous.

Marked variations in clay content occur in the solum of loess derived soils as a direct result of the differences in soil forming factors such as slope and vegetation. The C horizons are not as highly influenced by these factors and are thus more uniform in texture, color, and clay content. C horizons studied have all been leached and are non-calcareous. Slight variations in clay content are apparent in east-west traverses and possibly reflect a process of eolian sorting.

Glacial till is everywhere beneath the loess and is extensively exposed in rolling topography. The soil forming factors which play an important part in the development of the loess derived solum also act similarly in till horizons. Due to the greater thickness of till deposits and to the thickness of the overlying loess, leaching has progressed downward to an average of six or seven feet. Below this depth tills are highly calcareous.

The sandy silt layer which underlies the loess and which sometimes forms a part of the till solum exhibits strongly bi-modal sorting characteristics. It has undoubtedly originated under conditions of slope and rill wash contemporaneous with the initial increments of loess deposition.

Studies of particle-size distribution seem to be prerequisite to any attempt at soil stabilization. Well graded soils such as C horizon glacial till are stabilized more easily by either mechanical compaction or by the addition of stabilizing agents than for example the poorly graded gumbotils. High clay soils require significantly higher amounts of stabilizing agents than well graded sands. It can thus be readily seen that prior knowledge of particle-size distribution aids in the choice of the most durable and economic method of stabilization.

Clay minerals noted in this study were montmorillonite, illite, and kaolinite. Montmorillonite has the highest cation exchange capacity of these clays, and it may be that in certain kinds of chemical stabilization this high exchange capacity would permit a greater bonding action.

X-ray analysis of the detailed study samples is an extremely useful technique for the qualitative determination of the varied mineral types. Quantitative determinations are still in the trial and error stage but rough estimates may be made from inspection of peak intensities on the strip-chart record. No distinctive criteria for the distinction of different aged tills were observed.

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FINE SANDS IN EASTERN IOWA: A STUDY OF THEIR GEOLOGICAL AND ENGINEERING PROPERTIES

by

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INTRODUCTION

Sand is an important product of Iowa. The Bureau of Mines report[71] of 1952 shows that production of sand in Iowa was nearly three million short tons, with a value of almost 2⅜ million dollars. The most important uses of the sand are for building and road construction purposes, with lesser amounts used in molding sands, railroad ballast, for grinding and polishing, and as filter sand and engine sand.

Because Iowa is faced with the problem of finding suitable material for roadbuilding and surfacing material for roads and streets, attention has been directed to materials once considered unsuitable for these purposes. Fine sand is one of these materials. The sand is usually obtained from sources far removed from the actual construction sites and usually has to be processed to remove undesirable size fractions. Ideally in terms of time and costs the sand should meet the desired specifications for which it is to be used, and be located as closely as possible to the construction site. During the investigation of the loess in east-central Iowa, large deposits of fine-grained sands were observed along the Iowan drift border and the major drainage ways. A separate investigation of the sands in this area was therefore inaugurated, with an extension of the same study into northeastern Iowa.

The objectives of this study are:

(1) to determine the occurrence and distribution of the fine-grained sand deposits considered economically workable for engineering purposes in eastern Iowa, and

(2) to determine some of the physical, chemical, and engineering properties of four selected samples considered to be representative of the fine grained sand deposits.

The field work of the study was divided into two areas (figure 1). The east-central Iowa area includes Marshall, Tama, Benton, Linn, Johnson, Cedar and Clinton counties, the southeast part of Hardin County, and the northern part of Iowa and Scott counties. The northeastern area includes the northern part of Jones County and Jackson, Dubuque, Delaware, Buchanan, Fayette and Clayton counties.

PREVIOUS STUDIES

In all the previous studies on the geology and surficial deposits of eastern Iowa, very little work has been done on the fine-grained sand deposits. Some of these deposits are briefly mentioned by McGee (1890)[35] and in each of the geologic reports of the separate counties, and later reviewed in

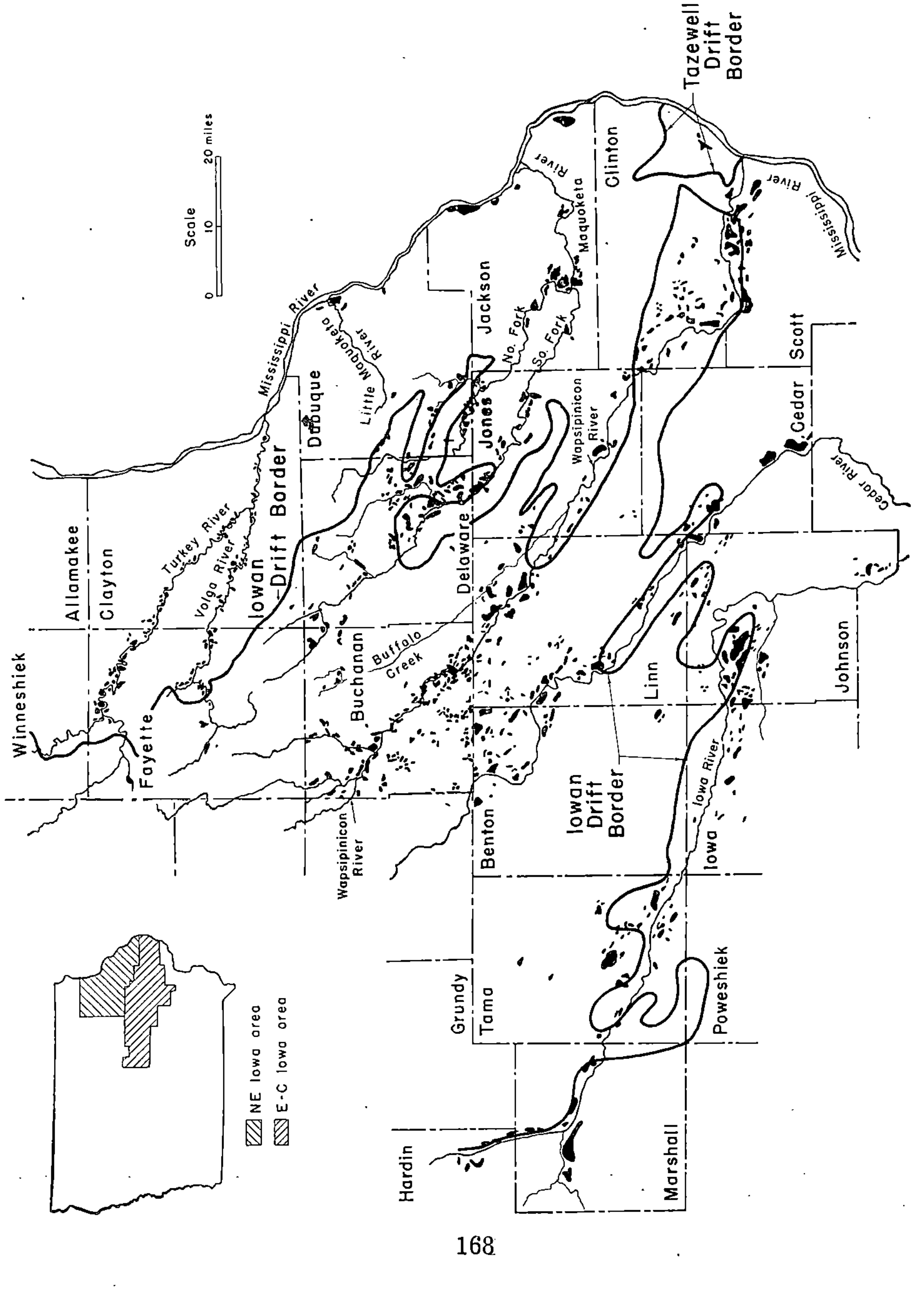


Fig. 1. Map of area showing the areal distribution of fine-grained sands in eastern Iowa.

more detail by Beyer and Wright (1914)[8]. Another early contribution was that of Udden (1898)[69]. Although none of his sand samples was from eastern Iowa, they are similar in nature to some of the deposits of the present study. Carmen (1909)[15], in his report on the geology of the Mississippi Valley between Savanna and Davenport, mapped and studied the field relationships of the sand in this area, but the majority of his sand studies were on the Illinois side of the river. Smith (1929)[48] made a survey of the molding sands of Iowa. These sands are finer textured and generally contain larger amounts of silt and clay than the sands of the present study. Many of them are sandy loess. Wickstrom, Riggs, and Davidson (1955)[76] reported on the occurrence and particle-size analysis of the fine grained sand deposits in east-central Iowa.

The above references deal mainly with the study of the sand in the field, its general appearance, its occurrence, its relationship to other deposits, and occasionally its particle-size distribution. There is little information on the mineralogical composition and on physical and chemical properties on these deposits. Williams (1953)[78] made a properties study of five Iowa sand samples. Although these samples were not from the area included in this study, his study is important because it seems to have been the first to include the mineralogical and other properties of sands from Iowa. The report includes the particle-size distribution, mineralogical composition, and behavior characteristics of the five sands.

Folks (1954)[21] determined the particle-size distribution and the chemical properties of some sand profiles. This information was used in this study in an attempt to evaluate profile development in sandy soils.

SAND IN EASTERN IOWA

Distribution and Occurrence

Fine-grained sand deposits are widely distributed in Iowa[1, 33-44]. In general, the sand in the southern part of the whole area occurs along the Iowan drift border and the major drainage ways. In northeastern Iowa, the sand is closely associated with the streams and the Iowan drift. In no place is the sand distributed as a vast blanket deposit like the loess, although sandy soil predominates in some areas.

The sands that occur along the drift border and a few miles away from the drift border and plain are closely associated with the loess. This relationship has been pointed out. Loess in east-central Iowa is distinctly sandier directly south of the drift border and the river flood plains, but the san dcontent decreased rapidly away from the border and flood plains[33]. The loess grades vertically and laterally into sand in Scott County but no sand is found a few miles south of the drift border[37]. Sand and loess are in close relationship in Scott County[15]. The material in the dunes of the bluff border area south of the Wapsipinicon River are of loess, sandy loess, and sand, intimately associated both horizontally and vertically. Similar relationships can be found in other places along the drift border where the loess is the thickest. The sand-loess association is also indicated on the Tama County soil survey map[1] where the sandy loess and silty sand is mapped as a sand-silt complex.

The loess is thin or absent on the Iowan drift plain, and the sand is closely associated with the drift. The sandy soils are derived from the sandy glacial drift, commonly reworked by the wind[46]. This relationship is especially true in the area of northeastern Benton County extending into Buchanan and Linn counties, and on the drift lobes in Johnson, Cedar, Clinton, Delaware, and Dubuque counties. In these areas the drift is very sandy and has been so reworked that the mappable sand is found in local accumulations within the sandy drift area. The following, on the elongated hills and ridges near the margin of the Iowan drift in northern Johnson County, states[11]:

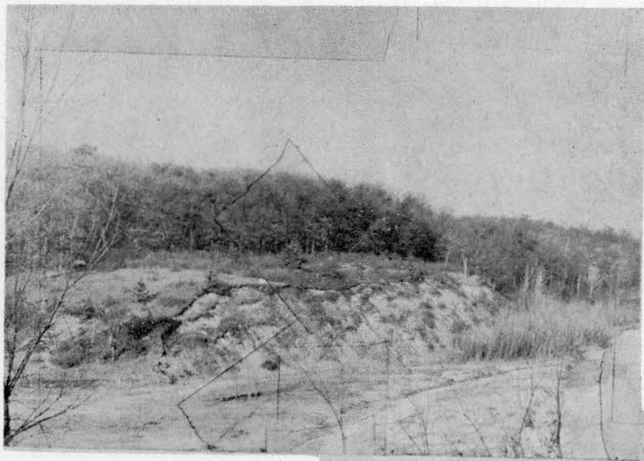
> These morainic ridges are composed largely of drift, but they contain more or less sand, and are not infrequently overlain at the summit by loess. A fine yellow sand is a very common constituent of these ridges, and the highest points are sometimes crowned with it.

Rounded hills and elongated ridges of sand are also in the southern part of the North Liberty lobe and over the whole area of the Solon lobe. These owe their origin to the period of melting and retreat of the ice. Similar deposits of fine sand can be found on other lobes of the Iowan drift.

For the most part, the sand deposits of Fayette and Clayton counties are associated with the rivers and some of the smaller tributaries. The sand appears to occur in two different types of terraces. One occurs high above the present flood plains of the major rivers and some of the secondary streams, and in high ravines cut into the limestone bluffs adjacent to the valleys. They are usually found up against the limestone bluffs, but some feet below it. The terraces along the Volga River in Fayette County are discussed as follows[8]:

> There are large quantities of fine, fresh light colored sands which extend up the slopes to the projecting cliffs of Niagaran limestone. In section 36, Illyia township, is a high hill of circumdenudation. On the south side of this hill the fine sands mentioned above extend to within forty feet from the top. In this case, then, the sands rise 160 feet above the river and in several cases they are 100 feet or more above the water.

Figures 2 and 3 are views of high terraces similar to the one described above. Figure 2 is a photograph of the terrace along a small creek in sections 7 and 17, Marion Township, Clayton County, where several of these terraces occur. Figure 3 is a photograph of the terrace that occurs between the limestone bluffs and the small creek in Section 11 of Westfield Township, Fayette County. The composition of the materials underlying these high terraces is very similar and consists mainly of rather fine, clean sand with some pebble size fragments of limestone and chert.



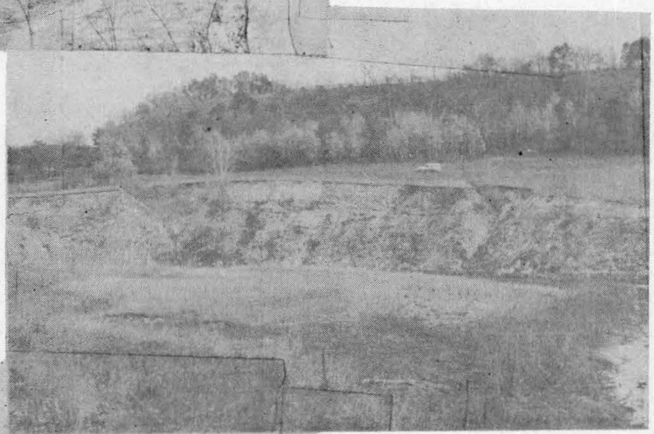


Fig 2., top. High terrace on the west side of small creek in section 17, Marion Township, Clayton County.

Fig. 3, center. High terrace along the east side of the small creek in section 11, Westfield Township, Fayette County.

Fig. 4, bottom. View of the dissected terrace in sections 2 and 3, Pleasant Valley Township, Fayette County. This terrace occupies a lower position than the terraces in figures 2 and 3.

The other terraces are lower and are usually found only along the major streams (figure 4). A typical one is 15 to 20 feet high and is of medium to coarse sand with varying amounts of gravel. The gravel is generally fine, but fragments up to 8 to 10 inches do occur. The composition of the gravel is mainly limestone, chert, and other rock fragments. In overall particle-size distribution the lower terraces are coarser textured than the high terraces.

These high and low terrace materials differ from the valley phase of the Buchanan gravels, usually largely of sand and fine gravel which are highly oxidized[13]. The sands contain less coarse material and are fresh and unweathered.

Other sand deposits are also found along some of the smaller streams in the area. In Minerva Township, Marshall County, sand is in the terraces and on the adjacent upland south of Minerva Creek. A similar relationship is also found south of Clear Creek near Tiffin in Johnson County. Sand deposits are also found along the banks of Otter Creek in Buchanan County, Honey Creek and Plum Creek in Delaware County, and White Water Creek in Jones and Dubuque counties. These deposits are generally coarser and are typical fluvial deposits.

A few sand deposits are related to abandoned river channels. Such a channel, once used by the Cedar River, is in Benton Township, Benton County. This channel is ¼ to 1 mile wide and extends in a southeasterly direction from the northwest corner of Benton Township into Linn County, where it meets the present channel. This old channel area was known as "Sand Prairie"[43].

An old river channel of the Wapsipinicon River has been reported on the east side of Central City in Linn County[36]. The lithology of a well sunk into this abandoned channel is reported as 4 feet of black soil and 96 feet of fine, yellow sand to bedrock.

Other abandoned channels were noticed in the area. On the south side of the Maquoketa River in Scotch Grove and Clay Townships, Jones County, is an old channel. It extends in a southeasterly direction from Section 12, Scotch Grove Township, where the present river makes a sharp bend into Clay Township and meets the present channel. That the sand in this area has been reworked by the wind is evidenced by a fairly well developed longitudinal dun pattern and some minor blowouts.

There appears to be another old channel in Sections 29 and 30 of Richland Township, Jones County. This channel begins in Section 30 where the Maquoketa River makes a sharp bend to the south. The old channel extends east across Section 29 and into Section 28, where the dissected topography makes it difficult to follow. Other abandoned channels may be found along the courses of the Maquoketa River in Jones and Jackson Counties, as well as the other rivers in the area.

Field Description

As previously mentioned, there are several different associations of the sand in the field. The sand deposits associated with the loess are finer textured and as a rule are more uniform, both areally and with depth. For the most part, no structures such as bedding and stratification are in these deposits, although some deposits do contain small lenses and layers of silt. Faint cross-bedding may also be seen near the surface in some of the sands that have been recently reworked. Some of these sands are intimately associated with the loess, both horizontally and vertically. Many of the mapped sand deposits are capped with varying thicknesses of silt. The contact between the sand and the silt, both at the top and sides, and at the bottom where observed, is usually gradual, being a silty sand with at times thin alternating layers of sand and silt.

The sand deposits associated with the streams are usually coarser textured and more variable than the sands associated with the loess. The materials in these deposits are more poorly sorted, the size of particles ranging from silt and clay to gravel. The amount of gravel is variable, but the composition of the gravel is usually limestone and chert, with other rock fragments less common. The limestone and chert is more common in the deposits in the northern and eastern part of the area where the limestone bedrock is closer to the surface.

Graded bedding and cross-bedding are common in these fluvial deposits. In several deposits, layers of very coarse material, and also some sections with very fine sandy silt layers were observed. These layers are less than one foot thick, and sand typical of the deposit occurs above and below the layers. Bedding near the surface of many of these sands is not as distinct, and the sand appears to be better sorted. This is probably due to the reworking of the material near the surface. The total thickness of the fluvial deposits usually was not determined, and therefore the bottom contact of the sand and the underlying material is not known. In those where the lower contact was observed, it was found to be fairly sharp, being a thin layer of silty sand above bedrock.

The sand deposits found on the till plain are usually intermediate in texture and sorting to the sands associated with the loess and those closely associated with the streams. The sorting is better near the surface where it appears to have been reworked. Bedding and stratification are also present in these deposits, but not as strongly exhibited as in the fluvial sands just mentioned. The sand at the surface is often quite silty. If that is so, it is mapped as a sandy loam on the published soil survey maps. The bottom contact with the underlying till is fairly sharp, usually being several inches of a sandy gravel material.

The surface material of many of the deposits has been reworked by the wind in varying amounts as shown by the mixing of the surface material, drifting, numerous blowouts, and dune pattern development. The deposits found on the till plain and the finer grained sands not capped with much silt appear to have been reworked the most. Fluvial deposits do not appear to have been reworked as extensively; the reworking probably being more localized.

Some of the surface material has been so reworked that differentiation of the soil horizons was not possible. Mixing of the surface and deeper in the profile has also been done by rodents. Those profiles were not separated into soil horizons and the material was sampled as a surface or disturbed layer. These surface horizons are usually higher in silt and contain appreciable amounts of organic matter.

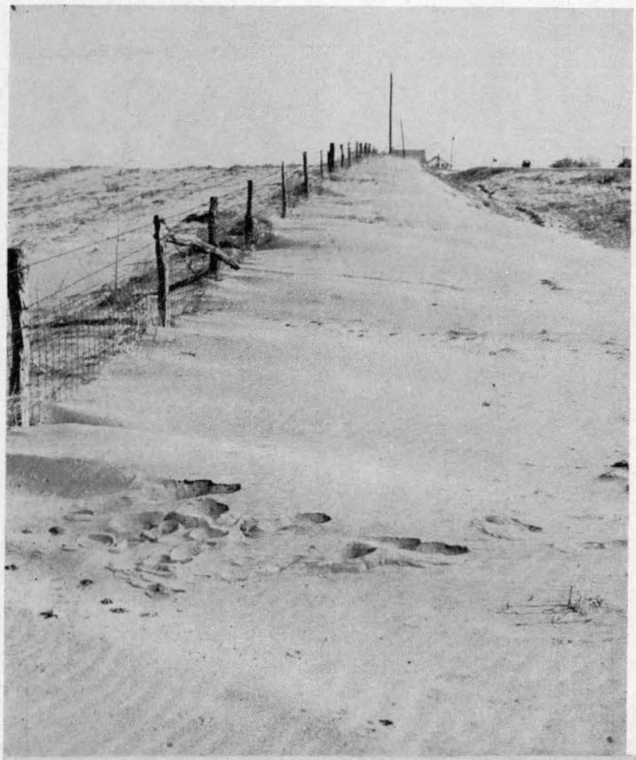
Drifting of the sandy surface material is shown in figure 5 where the material has drifted from the adjacent field that had recently been cultivated. The picture is of the sandy drift area north of Vinton in Benton County. Figure 6 is a photograph of a large blowout located in the NW¼ of Section 8, Maquoketa Township, Jackson County. That this whole area has been reworked is evidenced by other smaller blowouts, mixing of the surface material, and the billowy topography and dune pattern development seen on the aerial photographs.

The color of the sands is generally light yellow to yellowish-brown to brown, depending upon the amount of iron and its state of oxidation. Gray and unoxidized sands occur near the bottom of some sections. Darker colored sands are also present in some deposits and are usually higher in silt and clay and organic matter. These darker sands are more common in floodplain, terrace, and outwash deposits. The color of the surface material of the sands varies from pale brown to grayish-brown to black.

In many of the sand deposits reddish-brown bands were observed. A discussion of their occurrence and possible modes of origin is given in another part of this paper. So far as can be determined in the field, the bands seem to occur in all genetic and textural types of sand. However, it has not yet been established whether or not the bands occur more commonly in one type or another.

In thickness the bands vary from a fraction of an inch up to 6 inches, with bands of one to three inches predominating. The very thin bands have diffused contacts with the adjacent sand, and many have a wavy and contorted appearance (figure 7). Occasionally the band has the shape of a contorted ring, as if it had been formed around something (figure 8).

The thicker bands normally assume a horizontal position in a vertical cut, although Folks (1954)[21] found that the bands follow the slope of the land. They have also been observed to cut across bedding planes in the sand and to extend from fine sand into a coarser sand. The upper contact of the thicker bands and the adjacent sand is sharp as compared with that



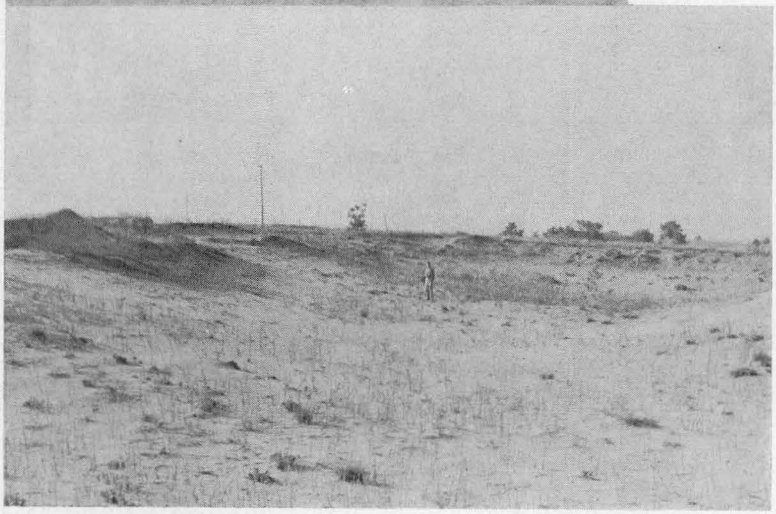


Fig. 5, above. Drifting of the surface material in the sandy soil area north of Vinton, Benton County.

Fig. 6, below. Large blowout in the sand in section 8, Maquoketa Township, Jackson County.

of the lower contact. Some of the thicker bands pinch out into thin bands (figure 9).

The thick bands were found in only a few sections. The series of thick bands found in Section S-10-3, Buchanan County, are from 4 to 6 inches thick, separated by lighter colored sand containing thinner bands (figure 10). The upper contacts are rather uniform and sharp; the bottom contacts irregular. The bands are rusty redbrown in color, and somewhat more indurated than most thinner bands. Mechanical analysis shows that the bands contain about 14 per cent silt and clay, and the interband areas contain only about 9 per cent silt and clay. Thick and uniform bands such as these are not as common as other bands.

Banding, or at least coloration similar to banding, is found along vertical and diagonal planes connecting the normal bands (figures 11 and 12). The impression given is that the sands have slumped and faulted, and that the banded material has accumulated along the slump and fault planes, probably due to water flowing along these planes.

Bands also appear to become concentrated and thereby form a zone of the banding material (figures 8 and 13).

Banding occurs most commonly from about 3 feet down to about 12 feet from the surface. Some bands do occur at shallower and deeper positions in the sections. In one section (S-33-1) bands were observed at a depth of

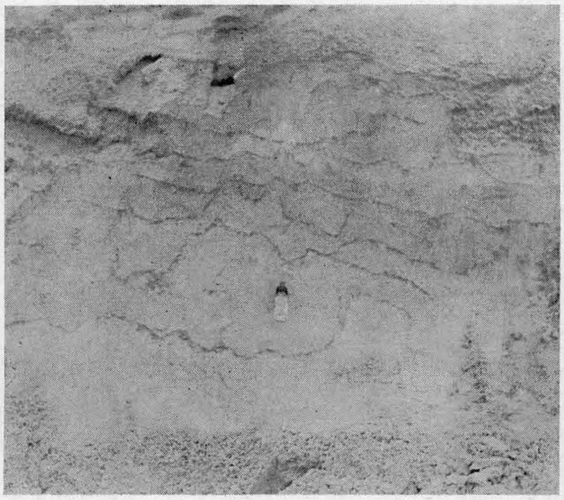


Fig. 7, above. Thin, wavy and contorted type of banding. The scale in the photograph is an acid bottle.

Fig. 8, at right. Banding in the form of rings. In the lower part of the photograph the bands become concentrated to form a zone of banding.

33 feet. The depth of banding and the thickness of the individual bands varies between deposits, as well as within the same section.

Of the 33 complete sections, all except 6 are completely leached of carbonates. Two sections associated with the loess and capped with silt are not leached as much as the other four sections. Section S-86-3 in Tama County is capped with three feet of silt; the sand is calcareous throughout the section. Section S-57-4, Linn County, is capped with a silty sand, and the sand is leached to about 8 feet. The other four sections that are calcareous are as follows: Section S-33-1 Dubuque County, below 19 feet; Section S-49-2 Jackson County, below 9 feet; Section S-52-3 Johnson County, below 13 feet; and Section S-52-4 Johnson County, below 10 feet.

The water table was found in 8 of the 33 sections. The depth of the water table ranged from about 6½ feet down to about 15½ feet. Two sections are from the old river channels. They are S-6-4, Benton County, with the water table at 6½ feet and sample S-53-4, Jones County, with the water table at 13 feet. Five of the sections are in deposits located on the Iowan till plain; the water table occurs at depths ranging from 9½ to 15½ feet. The remaining section, S-86-4, is located off the Iowan till plane less than 2 miles from the mapped Iowan drift border. The depth of the water in this section was at 15 feet.

From the available data it appears that the water table is more commonly

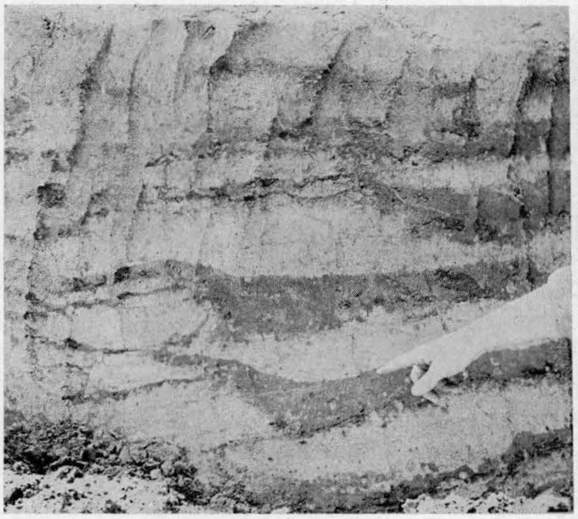
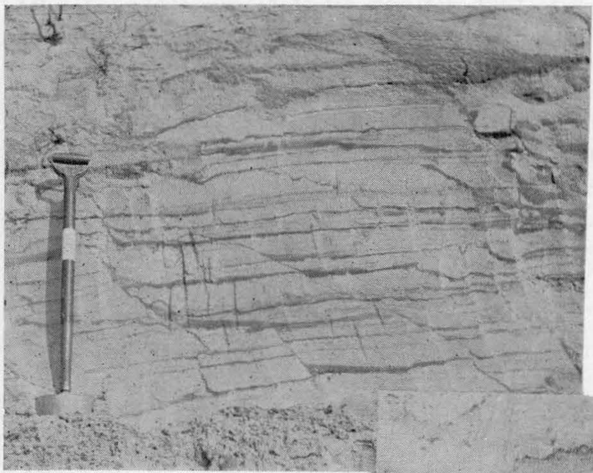
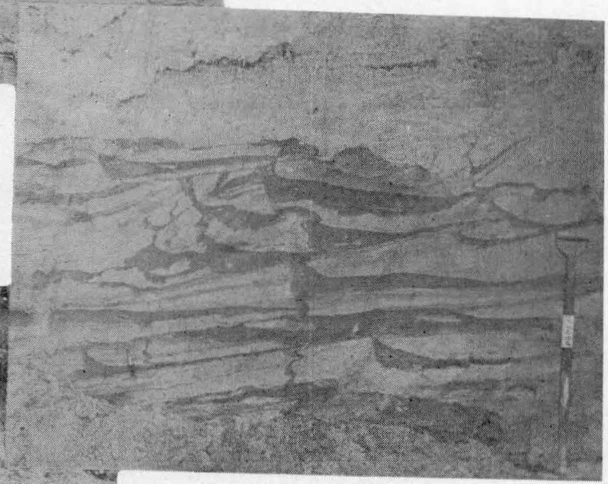


Fig. 9, above. Pinching out of thick bands into thin bands.

Fig. 10, at right. Series of thick bands in section S-10-3, Buchanan County. Note the thin bands in the lighter colored sand between the thicker bands.

higher in the sand deposits located on the Iowan till plain than in the other areas. This is due to the fact that the Iowan till is less permeable than the materials beneath the sands in other areas. A water table nearer to the





Figs. 11, top, and 12, above. Banding along vertical and diagonal planes connecting normal bands.

Fig. 13, left. Concentration of banding to form a zone-type of band accumulation. The section in S-6-2, Benton County.

surface in the sand deposits of the old stream channels would probably be the normal thing to expect.

There is no uniform trend in the total thickness of the sands, as could be expected with the scattered distribution. In most sample sites, the total thickness could not be determined with the augering facilities at hand. However it does appear that the thinnest sand deposits occur on the Iowan till plain. The thickness of the sands associated with the loess is variable, but appears to be greater than the thickness of the sands on the till plain. The sands associated with the streams are also variable in thickness, but as a rule are thicker than either of the associations mentioned above.

Origin and Classification

The origins of the sands in eastern Iowa are attributed to several different geologic agents. As is indicated in the discussion on distribution and occurrence of sand deposits, there are several different associations of sand in the field. The origin of the sands appear to be related to their associations in the field.

Most of the sands associated with the loess are believed to be wind deposited. Their source is the adjacent drift plain and nearby river flood plains. The source of the eolian sands appears to be quite local, probably no farther than a few miles in most instances.

Two kinds of sand deposits are found on the Iowan drift plain. One is the sands locally derived by wind reworking the sandy glacial drift to cause local accumulations. The other type found on the drift plain is derived from glacio-fluvial outwash. These deposits have not been appreciably reworked by the wind.

Sand deposits associated with the streams and occurring under terraces and flood plains are fluvial. Their source material is more variable than the other sand deposits, and much of it is undoubtedly derived from glacial outwash and till. The high terraces of Fayette and Clayton counties appear to be the result of the flooding of the previously cut river channels and backwater filling of the smaller tributaries with glacial detritus derived from the glacial outwash. All the high terraces are located east of the Iowan drift border. These major streams undoubtedly served as the run-off channels for the melt water which carried a capacity load, thus causing deposition. As these aggrading streams built up their valley floors, the smaller tributary valleys were probably flooded and filled with finer sediment. As deposition ceased and the streams once again became degrading, they eroded new valleys through the material deposited during the excessive run off, leaving some of the material that once filled the valleys high above the newly cut channels. The lower terraces were formed later by normal stream processes.

The sand deposits are classified according to their occurrence and association in the field and the character of the material. This is meant to be a genetic classification, with each deposit classified according to its most probable mode of origin. Since the origin of all the deposits could not be determined without more study, these deposits are grouped together as unclassified. Another group is included which is not part of the genetic classification. Although the origin of most of these deposits is known, they are included as of undetermined quality because they did not appear in the field to be of very good engineering quality as a fine sand. The sand deposits and their designated classifications are shown in figures 33 to 44 in appendix B. The classification with the assigned symbols is as follows:

Alluvial	
Fluvial	Flu
Glacio-fluvial	Fla
Eolian	Eo
Unclassified	Un
Undetermined quality	Uq

Alluvial refers to that which is transported by running water, the material deposited being alluvium. Since alluvial is a general term, the category is separated into two parts, fluvial and glacio-fluvial. The term fluvial designates a river as the agent responsible for the transportation and deposition of the material. In this classification are included the deposits found under terraces and floodplains. Glacio-fluvial sands are those formed by water flowing from melting glacial ice. Some of the fluvial deposits may be glacio-fluvial in origin, but this is difficult to distinguish. Where there was a question as to whether the sand was fluvial or glacial outwash in origin, the deposits were mapped as fluvial if they were closely associated with the present day streams and glacio-fluvial if they occurred on the till plain and away from any of the present day streams. The alluvial deposits have had little or no wind reworking.

The eolian category includes the sand deposits accumulated through the agency of the wind. They include most of the sand deposits associated with the loess and the deposits that occur on the till plain as the result of local accumulations of the sand by wind action.

The unclassified category includes the sand deposits in which the action of no single geologic agent appears to have been dominant. These sands may have been alluvial or eolian but have been modified by drifting, blowouts, erosion, and cultivation; so their origin is not identifiable without more detailed study.

Deposits of undetermined quality include the material that did not appear in the field to be a good quality fine-grained sand. It also includes the deposits which were inaccessible in the field, but from other indications, such as aerial photographs and soil survey maps, they appear to be good sources of sand. Some of these are alluvial sands found in terrace, flood plain, and outwash deposits. They contained too much fine material or too much gravel to be considered as fine-grained sand. Others consists of the very silty sands and interbedded sands and silts that are mapped as sand-silt complexes on the soil survey maps. Many of these deposits undoubtedly contain appreciable amounts of fine sand, but it would be necessary to process the material to obtain the sand. A more detailed study of these coarser sand-gravel mixes and sand-silt deposits may also prove to be very useful; they may be natural mixes meeting specifications for certain engineering purposes.

FIELD PROCEDURES

Method of Mapping

The mapping of the sand was done by field reconaissance with the aid of agricultural soil survey maps and aerial photographs. The general procedure was to locate potential sandy areas by using the soil survey maps and photographs. These areas were then drawn on county base maps. As many of these areas as possible were then visited to determine whether or not the deposits were to be included in the study.

Since there is no way to foresee future engineering specifications for the sand, the deposits were mapped regardless of quality. Separation of what appeared to be sand of good quality from sand of poor quality would not be practicable from a limited field reconnaissance of this kind. It is also possible that the character of the sand within an individual deposit will vary considerably. A deposit is shown on the county and sand location maps if the sand is at least 5 feet thick without an appreciable amount of overburden and if there is enough of it to be workable for engineering purposes (figures 33 to 44).

To make the soil survey maps more useful to the geologist and engineer, because many of the soil series names have changed considerably throughout the reports, a brief correlation of the sandy soil series mapped is given. In the old Iowa Agricultural Experiment Station soil survey reports, the sandy soils were generally mapped as drift soils, loess soils, and terrace or bottomland soils. For the most part we shall be concerned with only the upland soils.

Knox fine sand was mapped as a loess soil in Scott County in 1919, in Marshall and Cedar counties in 1922, and in Johnson County in 1923. In many instances, the Knox series is the same as the Lindley sandy soil series mapped in adjacent counties, although the Lindley series is mapped as a drift soil. This discrepancy appears to be due mainly to lack of definition and nomenclature on the part of the surveyors.

Lindley fine sand as mapped in Jones County in 1929 is also the equivalent to at least some of the Sparta sand identified in Jackson County in 1941. Some of the terraces along the Mississippi River are also mapped as Sparta sand, but these probably should be mapped differently from the more upland sands that occur in Jackson County.

A difference also appears in the Lindley sandy soils previously mentioned and the Lindley sandy loams mapped in Fayette County in 1923, and in Clayton County in 1930. Although it must be remembered that the textural designation given on the soil maps is only for the soil profile, the occurrence and composition of the sand is different from the other Lindley sandy soils. Most of the Lindley sandy loam mapped in Clayton and Fayette counties occurs in high terraces along the major streams and some of the smaller tributaries[8]. For the most part they are fine, clean sand with a little limestone and chert fragments of pebble size.

Generally speaking the Carrington sandy soil is very similar throughout the area. The Carrington sandy loam is fairly widespread, but very little of this type of sandy soil proved to be worth while. It was mapped only where it has locally accumulated within the sandy soil areas. The same is also true for Dickenson sandy loam, which differs from the Carrington sandy loam only in having a thicker sandy material over the underlying till. In many places the boundaries between the two are not exact, and therefore they may be mapped as one.

The Carrington sand mapped in Benton County in 1927 is probably the same as the Dickenson loamy sand mapped in Buchanan County in 1932. Although their surface texture designation is different and the Dickenson is supposed to have a coarser texture, their occurrence is similar, being associated with the sandy phases of the drift. Some of the Carrington sand may also be the same as the Knox and Lindley sand.

Shelby sandy soils, which are also associated with the Carrington series, would appear to be also related to the Carrington and Dickenson sandy soils. The Shelby loamy sands and sandy loams as mapped in Scott County in 1919, in Dubuque County in 1924, and in Delaware and Jones counties in 1929 are supposedly derived from sandy Kansan drift. There is some question as to the probability of this. The fact that the Shelby series in this area is closely associated with the Carrington series suggests that the Shelby sand is younger than the Kansan. The character of the Shelby sand resembles the Dickenson sand more than the Carrington sand, and probably would be mapped as Dickenson on the more recent soil maps. As with other loamy sands and sandy loams, the only mappable deposits in the Shelby series occur as local accumulations within the sandy soil areas.

In Tama County the upland sandy soils were mapped as Thurman loamy fine sand and Chelsea loamy fine sand, depending on the color of the soil profile[1] and both are defined as windblown sands[46]. Thurman is the dark-colored sandy soil presumably formed under grass vegetation, and Chelsea the light-colored sandy soil formed under a forest vegetation. The Thurman is equivalent to the Carrington sand and perhaps some of the Lindley and Knox, depending on the color of the soil. Chelsea is the same as the Knox, Lindley, and the upland phase of the Sparta sand. Chelsea is also equivalent to some of the Plainfield sandy soils as mapped in eastern Iowa.

In future soil surveys, the Thurman series will probably be dropped in favor of the Hagener series, a sand mapped in Illinois[40]. This will represent the dark colored sand with a loamy fine sand B horizon. Chelsea will be continued as the light-colored sand with a loamy fine sand B horizon. Dickenson, which is derived from sandy glacial drift usually reworked by wind, will be mapped as the dark-colored sand with a sandy loam B horizon. Lamont series will represent the light-colored, or forest equivalent of the Dickenson[40]. Texturally, the Dickenson and Lamont series is generally coarser than the Hagener and Chelsea series.

Sampling

The areal distribution of the sand and the number of sandy soil series represented determined the number of samples taken throughout the area (table I and figures 33 to 44). At least one complete profile was sampled from each of the major sandy soil series. Additional C horizon samples were randomly selected throughout the areas as check samples.

Sampling of the solum and as much of the C horizon as possible was done to show both the variation in particle size with depth and the amount of overburden above the C horizon sand. Since the material from the solum probably would not be used for engineering purposes, it is considered as overburden. The A and B horizons in the sandy profile cannot always be separated, and therefore the A and B horizons are grouped together. Any material unsuitable for soil stablilization and other engineering construction that would be found in the A horizon would also probably be in the B horizon due to its porous nature, and therefore the A and B would be stripped off together.

Sampling was usually at hilltop positions in road cuts or in natural banks. The cut was cleared of slump to expose the section and to take the samples. Where road cuts and banks were not available, a pit was dug for sampling the solum. Samples from deeper than the pits and road cuts were obtained with a four inch auger. Composite samples were taken of the solum and the part of the C horizon (table I).

The sample numbers used in this report are designed to indicate by number the county from which the samples were taken. The initial S identifies it as a sand study sample to avoid confusion with loess samples of another study. The middle numbers, such 6, 23, 42, 52, for example, are the individual county numbers of Benton, Clinton, Hardin, Johnson. The last figures are the numbers of separate sections or check samples obtained in each particular county.

SELECTION OF SAMPLES FOR DETAILED ANALYSIS

Four C horizon samples were chosen for analysis to obtain physical, chemical, and petrographic data (table I and figures 35, 37, 40, 42). For data to be used for soil stabilization studies, the samples were selected to repre-

TABLE I. SAMPLING LOCATIONS OF SAND IN EASTERN IOWA

Sample No.	County	Section	Twp.	Range	Horizon & Depth Sampled Solum	C	Soil Series
S-6-1	Benton	NW¼,SW¼,S-2	86N	11W		9′-10′*	Carrington sand
S-6-2	Benton	NE¼,SE¼,S-16	86N	10W	0-1′6″	1′6″-16′-6″	Carrington sand
S-6-3	Benton	NW¼,SW¼,S-25	86N	9W		5′6″-10′*	Carrington sandy loam
S-6-4	Benton	NW/C,NW¼,S-29	85N	9W	0-2′6″	2′6″-6′6″	Carrington sand
S-23-1	Clinton	SW¼,NE¼,S-17	81N	2E	0-3′	3′-9′6″	Carrington fine sand
S-23-2	Clinton	SW/C,SW¼,S-13	82N	1E	0-3′6″	3′6″-15′-6″	Carrington fine sandy loam
S-42-1	Hardin	E½,NE¼,S-30	87N	19W		6′*	Carrington fine sandy loam
S-52-1	Johnson	NW¼,SW¼,S-7	77N	5W		3′6″-13′6″	Knox sand
S-52-2	Johnson	NW¼,NW¼,S-18	80N	8W		10′-20′	Knox sand
S-52-3	Johnson	NW¼,SW¼,S-8	80N	7W		5′-23′	Knox sand
S-52-4	Johnson	NE¼,NE¼,S-11	81N	6W		2′-14′6″	Knox sand
S-52-5	Johnson	SE¼,SE¼,S-6	81N	6W		3-8′6″*	Knox sand
S-53-1	Jones	SW¼,SW¼,S-6	83N	2W	0-3′6″	3′6″-13′9″	Lindley fine sand
S-53-2	Jones	SE¼,SE¼,S-18	85N	4W		5′-8′*	Lindley fine sand
S-57-2	Linn	E½,SW¼,S-12	84N	8W	0-1′6″	1′6″-14′	Lindley fine sandy loam
S-57-3	Linn	SW¼,SE¼,S-27	86N	6W	0-3′	3′-12′	Lindley fine sand
S-57-4	Linn	NE¼,SW¼,S-10	82N	6W		1′-25′	Lindley fine sandy loam
S-64-1	Marshall	NE/C,NE¼,S-2	84N	19W		6′-8′*	Knox loamy fine sand
S-64-2	Marshall	SE¼,NE¼,S-10	84N	19W		2′-15′	Carrington fine sandy loam
S-64-3	Marshall	SW¼,NE¼,S-17	84N	18W		3′6″-12′	Knox loamy fine sand
S-82-1	Scott	NW¼,NW¼,S-17	80N	3E	0-3′6″	3′6″-14′	Shelby loamy fine sand
S-86-1	Tama	SE¼,SW¼,S-9	82N	13W		8′-20′	Tama-Thurman complex
S-86-2	Tama	S½,NE¼,S-30	83N	15W		8′-13′*	Fayette-Chelsea complex
S-86-3	Tama	SE¼,SE¼,S-3	82N	15W		3′6″-20′	Thurman loamy fine sand
S-86-4	Tama	SW¼,NE¼,S-8	82N	13W		6′-15′	Chelsea loamy fine sand
S-10-1	Buchanan	SE¼,SW¼,S-7	87N	9W		5′4″-5′10″	Dickenson sandy loam
S-10-2	Buchanan	NE¼,NW¼,S-32	87N	7W	0-1′3″	1′3″-13′6″	Lindley sand
S-10-3	Buchanan	SE¼,NW¼,S-3	89N	10W	0-2′1″	2′1″-12′9″	Dickenson sandy loam
S-10-4	Buchanan	NW/C,NE¼,S-26	87N	9W	0-2′2″	2′2″-12′10″	Dickenson loamy sand
S-28-1	Delaware	NW/C,SW¼,S-15	89N	6W		2′6″-3′*	Carrington sandy loam
S-28-2	Delaware	SE/C,SW¼,S-1	88N	5W	0-6′	6′-13′6″	Carrington sandy loam
S-28-3	Delaware	SE¼,SE¼,S-2	89N	5W	0-2′1″	2′1″-13′1″	Carrington sandy loam
S-28-4	Delaware	SE¼,NE¼,S-18	87N	3W	0-3′2″	3′2″-12′8″	Shelby sandy loam
S-28-5	Delaware	NW¼,SW¼,S-36	89N	4W	0-3′10″	3′10″-22′11″	Lindley sandy loam
S-31-1	Dubuque	NE¼,NW¼,S-23	87N	1W	0-1′4″	1′4″-16′4″	Lindley fine sand
S-33-1	Fayette	S½,SW¼,S-11	93N	8W	0-1′	1′-38′	Lindley sandy loam

Table I. Continued

S-49-1	Jackson	NW/C,NW¼,S-7	84N	3E	0-8′	8″-13′	Sparta sand
S-49-2	Jackson	NW¼,NW¼,S-8	84N	3E	0-4′	4′-17′6″	Sparta sand
S-49-3	Jackson	NW¼,SE¼,S-15	85N	2E	0-2′8″	2′8″-7′2″	Sparta sand
S-49-4	Jackson	SE¼,SW¼,S-12	84N	1E	0-2′	2′-8′6″	Sparta sand
S-53-3	Jones	SW¼,NE¼,S-29	86N	2W		4′6″-5′* 12′-12′6″*	Lindley fine sand
S-53-4	Jones	SW¼,SW¼,S-7	85N	1W	0-3′3″	3′3″-14′3″	Lindley fine sand
S-53-5	Jones	SE¼,SW¼,S-5	86W	3W	0-4′8″	4′8″-14′6″	Lindley fine sand

* Check samples

sent the particle size range of all the composite C horizon samples of the area (figure 17). The selected samples are:

S-57-4 (6′ to 13′): median diameter 0.154 mm.
S-6-2 (3′ to 6′): median diameter 0.240 mm.
S-28-4 (3′2″ to 9′8″): median diameter 0.292 mm.
S-31-1 (1′4″ to 10′4″): median diameter 0.350 mm.

Section S-57-4 is located on the upland in a sand-silt complex region between two lobes of the Iowan drift and approximately a half a mile southeast of the Cedar River flood plain. The surface material is silty and disturbed and was not sampled. The upper six feet of the section is high in silt and clay and contains numerous bands. The sand gradually becomes

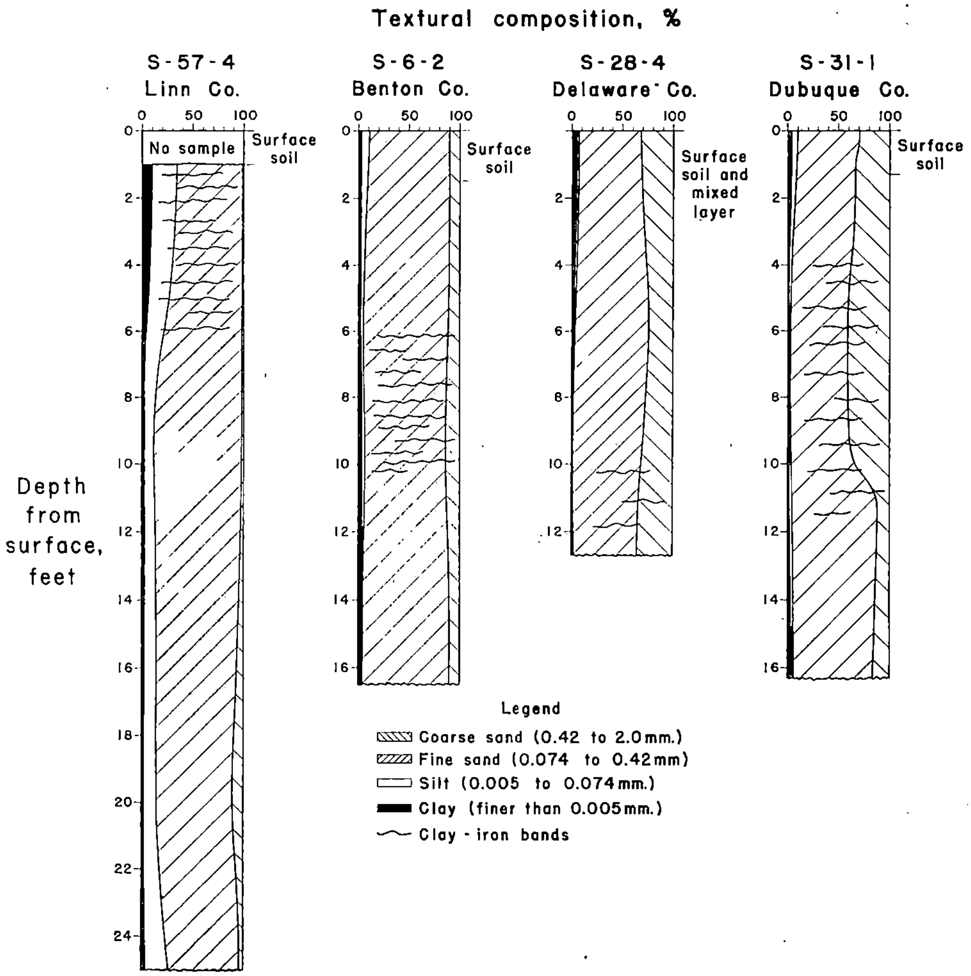


Fig. 14. Variation of textural composition with depth of the four sections selected for detailed analysis. The configuration and width of the clay-iron bands only represents their presence, not their shape and thickness.

coarser near the bottom, and the lower two feet again become a silty sand grading into a sandy silt material. The sand is leached to approximately eight feet below the surface (figure 14).

Section S-6-2 is located near the southeast end of an elongate hill that trends in a northwest-southeast direction (figure 13). It is on the Iowan drift plain and approximately three-quarters of a mile southeast of the Cedar River flood plain. The adjacent hills to the north and south are loess and would probably be called pahas. The upper foot and one-half of the section is silty, grading into a well sorted sand, gray-brown to light yellowish brown in color, and containing thin bands. At a depth of 6 feet a zone of banding begins and continues to about 11 feet. These bands are fairly well indurated. The entire section is noncalcareous.

Section S-28-4 is from the northwestern flank of a crescent-shaped hill pointing toward the east. Blowouts occur to the southeast of the sample location. The upper three feet is black to dark gray and has been mixed by rodents. The percentage of silt and clay gradually decreases with depth. Near the bottom the sand becomes a little coarser, and light yellow streaks appear. The water table is at eleven feet; the high water table in this section is probably due to a perched water table upon bedrock, which is exposed at the surface at some places in the area. The color of the sand below the water table is gray. The whole section is noncalcareous.

Section S-31-1 was obtained near the east end of a sandy area located between the fork of two small streams and approximately one mile northeast of the mapped Iowan drift lobe. The surface material is a gray to black sandy soil containing a few chert fragments up to half an inch in size. This layer grades into a light gray to tan silty sand, which in turn grades into a light brown sand containing bands one-eighth to half an inch in thickness. The bands gradually thicken to about one inch, and at ten feet they again become thin and seem to diminish. The texture of the sand also becomes finer at ten feet, and there is a gradual increase in the amount of silt and clay with increasing depth. The silt and clay occurs in thin layers and lenses. Small fragments of chert are scattered throughout the sand. At about fifteen feet the chert content increases, and the fragments increase to about one inch in size.

LABORATORY METHODS AND PROCEDURES

Mechanical Analysis

Mechanical analysis of all the sand samples were performed by the sieving and hydrometer method (A.S.T.M. Designation D422-54T) (A.A.S.H.O. Designation: T88-49) as modified[16]. Sodium metaphosphate was used as the dispersing agent. The fraction retained on the No. 200 sieve was dry sieved using the following sieves: No. 20, No. 40, No. 60, No. 100, No. 140, and No. 200. The size classification used throughout this report (A.A.S.H.O. standard

1950, and A.S.T.M. 1954) is coarse sand 0.42 to 2.0 mm. diameter, fine sand 0.074 to 0.42 mm. diameter, silt 0.005 to 0.074 mm. diameter, and clay less than 0.005 mm. diameter.

Physical Tests

A number of standard engineering tests were performed to determine some of the physical properties of the sand. These properties are used to predict performance of the sand when it is used as a construction material. The tests were conducted on the samples selected for detailed analysis. The test and the test methods are as follows:

(a) Specific gravity, by the pycnometer method (A.S.T.M. Designation: D 845-50T)[2].

(b) Atterberg limits (A.S.T.M. Designations: D 423-39 and D 424-39[2]. The liquid limits were also determined by another method[67]. Though the sample is prepared in the same way, the special technique for sandy soils uses an evaporating dish instead of the standard appartus.

After smoothing the sandy soil into a layer approximately ⅜ inch thick against the sides of the dish, a groove is made in the sample with the grooving tool. The dish is held in the right hand by the edge opposite the groove, and lightly struck ten times down against the heel of the left hand, which is held vertically and with the heel up. The groove should be horizontal and directly above the point of contact with the hand. When the groove closes for at least ½ inch in length ,the groove should be pushed apart with a spatula. If the groove does not completely open, the soil is at the liquid limit. If the groove closes under ten blows, but is opened completely with one push of the spatula against one side of the groove, the moisture content is less than the liquid limit. In this case, add and mix thoroughly a small amount of water, and repeat as before. Tap the dish against the heel of the hand for ten blows, even though the groove may close at a smaller number of blows. Again push against one side of the groove. If the groove completely opens up, repeat the addition of moisture and tapping ten blows until the groove does not open with one push of the spatula. When the liquid limit moisture content is reached, the percent moisture is determined in the usual way.

(c) Textural classification (U.S. Bureau of Public Roads System)[72].

(d) Engineering classification (revised Bureau of Public Roads System, A.A.S.H.O.[2]

(e) U.S.D.A. classification[73].

(f) Standard Proctor density and optimum moisture content (A.A.S.H.). Designation: T 99-49,[3]

(g) Permeability, by Barber's method[4] as modified[17]. The modifications are as follows: (1) loading the air-dried material into the tube by the inverted method using four equal layers to avoid segregation of the coarse and fine particles, (2) treating the material in the tube with carbon dioxide to remove air from the sample, and (3) repeating the testing of the loaded sample, until the permeability values obtained are practically uniform throughout the test.

The permeability of the selected samples was run under three sets of conditions: (1) inverted method of loading with no CO_2 treatment; (2) inverted method of loading and treating with approximately 0.45 cubic feet of carbon dioxide at the rate of 0.03 cubic feet per minute, and (3) loading and treating as in 2, followed by compaction of the samples to approximately 100 per cent of Standard Proctor density. Compaction was accomplished by tamping the tube with a 4 pound weight resting on the sample.

Chemical Tests

Chemical tests on the samples selected for detailed analysis were conducted. The tests and test methods include:

(a) pH, by a Beckman glass electrode pH meter.
(b) Carbonate content expressed as per cent $CaCO_3$, determined by a volumetric measurement of CO_2 evolved from the acid decomposition of the carbonates in the soil[18].

(c) Free iron content, by a method using 20 milliliters of orthophenanthroline instead of one milliliter as indicated in the procedure[66].
(d) Organic matter, by a dichromate oxidation method[18].

Preparation of Samples for Petrographic Analysis

Separation into size fractions

The ideal method for determining the mineralogy of sand is by separation of the original sample into size fractions having as narrow a range as possible and separating each of these into a light and heavy fraction.

To separate the sample into size fractions, the four samples selected for detailed analysis were prepared the same as for mechanical analysis. The oven-dried material was then sieved on the following nest of sieves: No. 20, No. 40, No. 60, No. 100, No. 200 and No. 325. Because the material passing the No. 325 sieve (44 micron) contains only a small percent of the whole sample, this fraction was not saved for petrographic analysis.

Separation into light and heavy minerals

Each of the above size fractions was separated into light and heavy minerals by flotation in bromoform ($CHBr_3$), which has a specific gravity of 2.87 at 20°C. Many methods have been devised for the separation, but no single method was found satisfactory for all the size fractions of the sand. Krumbein and Pettijohn (1938) discuss various methods and apparatus, and outline a method (p. 343) for the separation of heavy minerals.

Two methods were used for the sands; one for the fractions larger than .074 mm., the other for the fraction smaller than .074 mm. A glass stoppered cylindrical separatory funnel with a stopcock in the stem was used for the larger fractions. A 1 to 2 gram portion of the oven-dried sample was poured into the funnel that was about three-quarters filled with bromoform. The grains were then stirred and washed down from the sides and off the stirring rod with bromoform. The funnel was then stoppered and allowed to set for several minutes to allow the heavy minerals (specific gravity greater than 2.87) to settle. This process was repeated several times to assure completeness of separation. The heavy minerals were then drained through the stopcock into filtering crucible, and the remainder of the bromoform and light minerals into another filtering crucible. The funnel was then rinsed out with acetone, catching the rinse in the crucible containing the light minerals. After washing in acetone and oven-drying, the light and heavy mineral fractions of the size groups were weighed on an analytical balance.

The heavy mineral separation of the .044 mm. to .074 mm. size fraction was performed by using the special double glass centrifuge tubes[78]. The material was oven-dried to eliminate water films which prevent wetting of the grain surfaces by the bromoform. The sample was placed in the inner tube and stirred, then the tubes were stoppered and centrifuged for several minutes at 1500 rpm. Several repeated stirrings and centrifugings were necessary to make a separation complete. The light minerals remain in the inner tube, and the heavy minerals settle from the inner tube through a small hole into the larger outer tube. The tubes are then separated, and the contents are filtered, washed, and dried as in the procedure for the larger fractions.

Mounting

Permanent slides of the minerals were made of each size fraction of the light minerals and of the .044 to .074 mm. size fraction of the heavy minerals. The light minerals were mounted in Ladeside No. 70 cement, which has a refractive index of 1.54[26]. This is a satisfactory medium whose refractive index can be used to separate quartz from most of the feldspars. Piperine, which has a refractive index of 1.68, was used to mount the heavy minerals. This index of refraction aids in the separation of the amphiboles from the pyroxenes.

Mineral Determinations

Mineral determinations were made with a Leitz petrographic microscope by identifying the grains along traverses. At least 100 grains in each size fraction of the light minerals and 200 grains of the heavy minerals were identified. These were converted to percent of the whole samples. The necessary corrections were made in the light and heavy mineral percentages due to incomplete separations.

Grains identified as "with clay coatings" and "with iron coatings" revealed such coatings in varying amounts, even after dispersion and bromoform separation. Altered feldspars include these in which at least part of the grain is converted to some alteration product. Opaque minerals of the heavy mineral fraction were identified largely on the basis of color, shape, and surface texture with the aid of a low angle incident light.

Sphericity and Roundness Determinations

Sphericity, or shape, and roundness are fundamental properties of sediments which reveal the mode of transportation, conditions of deposition, history of abrasion ,and maturity of the sediment. Wadell (1932) was the first to differentiate between sphericity and roundness. Sphericity and according to the following equation:

$$\text{Sphericity} = \sqrt[3]{\frac{\text{Volume of particle}}{\text{Volume of circumscribing sphere}}}$$

Recognizing that the circumscribing sphere is based on the maximum dimension of the particle, the equation is reduced to:

$$\text{Sphericity} = \frac{\text{Nominal diameter}}{\text{Maximum intercept}}$$

It follows then, that a particle whose dimensions are equal will have a sphericity value the same as that of perfect sphere, or 1.0. All other particles whose dimensions are not equal will have values less than 1.0.

To simplify the measuring of intercepts, a visual method of estimating two-dimensional sphericities based on Krumbein's equation makes use of a chart showing the outlines of 135 grains of varying sphericities[41]. By comparing a sufficiently large number of sand grains with the outlines of known sphericity, this method can be used satisfactorily and was employed in this investigation.

Roundness pertains only to the sharpness of the edges and corners, and is independent of sphericity. Wadell (1932) expressed roundness as:

$$\text{Roundness} = \frac{\text{Average radius of corners and edges}}{\text{Radius of maximum inscribed circle}}$$

As the average radius of the corners approaches that of the inscribed circle, the roundness value approaches 1.0. A two-dimensional chart for roundness which has 87 images of known roundness was used in this study[28].

Sphericity and roundness values were measured by examining grains along traverses under the petrographic microscope, using the permanently mounted slides. In using the two-dimensional methods, it was assumed that the grains were lying flat so that the maximum and intermediate diameters would be in the plane of the slide. Because heavy minerals contain only a small per cent of the total sample, they were not measured.

Clay Mineral Studies

Extraction of clay

Two size fractions of the samples selected for detailed study were separated for clay mineral analysis. They are the minus 0.044 mm. (No. 325 sieve) and the minus 0.002 mm. sizes. The material finer than 0.044 mm. was obtained by two methods: one by dry sieving on a No. 325 sieve, the other by soaking the sample in water and then wet sieving on the No. 325 sieve. The wet sieve material was dried in an oven at 60°C. and then was ground in a mortar.

The material finer than 0.002 mm. was obtained by means of a pipette extraction apparatus. The samples were agitated in 1000 ml. hydrometer jars and allowed to settle the required time necessary for 0.002 mm. (2 micron) clay to settle 5 cm. depth, and the extraction was made by applying a constant, slow suction. This process was repeated until a sufficient amount of clay was collected. The clay suspensions were then oven-dried at 60° C. and ground in a mortar.

Differential thermal analysis

Differential thermal analysis is a method which determines the temperature at which thermal reactions take place in a material when heated at a constant rate to an elevated temperature alongside an inert material. This method is used as an aid in identifying clay minerals in soils. As the two specimens are gradually heated to 1000° C., chemical and physical changes take place in the sample causing a temperature difference between the sample and the inert material. These temperature differences are measured and recorded, along with the temperature at which they occur. Because different minerals produce reactions that are diagnostic of themselves, the unknown samples can be interpreted by comparing the reactions with those produced by known minerals.

The apparatus used for this study has two furnaces, one of which can be run while the other is cooling[27]. The furnaces are controlled by an on-off controller heating the sample block at a linear rate of 10° C. per minute. The sample holders are made of chrome-nickel stainless steel and contain the two holes for the sample and the inert material. The thermocouple wire consists of two lengths of 22 gauge pure platinum wire spot welded to a shorter length of Pt 10% Rh wire. Temperature and differential thermal reactions are recorded on separate strip chart recorders[24, 32].

All samples were kept in an atmosphere of 50 to 55 percent relative humidity for about two weeks prior to analysis. Maximum temperatures used were slightly above 1000° C. Calcined alumina was used as the inert material. Interpretations were made by comparing the thermal curves obtained in the study with other curves[22, 23, 27, 50] and with reference curves run on this apparatus.

Observations of Coatings

Coatings, believed primarily to be clay, cover the surface of the un-

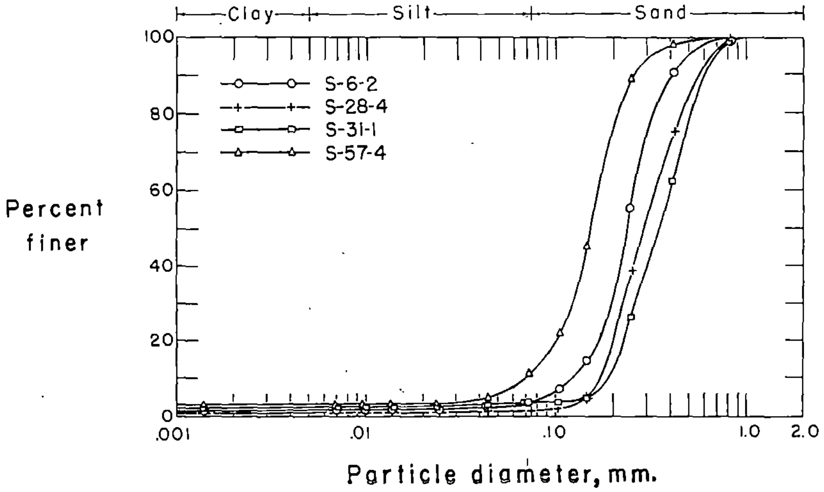


Fig. 15. Particle-size distribution curves for the four sand samples selected for detailed analysis.

cleaned sand grains in varying amounts. In samples that contain appreciable amounts of clay, the sand grains tend to aggregate into larger units cemented by the coatings. The coatings were observed using the petrographic microscope and the binocular microscope. In using the petrographic microscope, the uncleaned grains were mounted in temporary slides using immersion oils.

PRESENTATION OF DATA

Particle-Size Analysis

Particle-size distribution curves for the four samples chosen for detailed study are shown in figure 15. Tabulated figures for the different size fractions, including sample S-6-2 (6′-11′) are given in table II. The range in the particle-size distribution curves for all the C horizon samples, including the check samples, is shown in figure 16.

Except for the different size fraction that each selected sample represents,

TABLE II. TEXTURE, QUARTILE MEASURES, AND GRADING VALUES OF THE DETAILED STUDY SAMPLES.

	S-6-2 (3′-6′)	S-6-2 (6′-11′)	S-28-4 (3′2″-9′8″)	S-31-1 (1′4″-10′4″)	S-57-4 (6′-13′)
Sand, % 2.0 to 0.42 mm.	9.1	12.9	24.4	37.0	1.7
Sand, % 0.42 to 0.074 mm.	87.7	81.5	74.4	59.2	86.9
Silt, % 0.074 to 0.005 mm.	1.7	1.6	0.2	1.6	8.6
Clay, % less than 0.005 mm.	1.5	4.0	1.0	2.2	2.8
Median diameter, mm	0.240	0.241	0.292	0.350	0.154
First quartile, mm.	0.168	0.180	0.212	0.245	0.112
Third quartile, mm.	0.305	0.335	0.420	0.485	0.197
Sorting coefficient, So	1.28	1.36	1.41	1.41	1.33
Uniformity coefficient	2.14	2.57	1.96	2.12	2.45
Effective Size, mm.	0.122	0.105	0.172	0.189	0.069

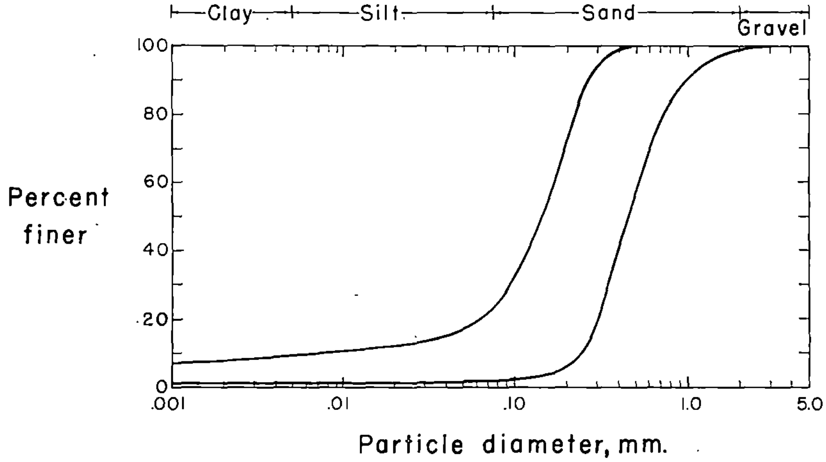


Fig. 16. Range of particle-size distribution curves of all C horizon sand samples, including check samples.

the shapes of the curves was very similar. All samples contain low percentages of silt and clay; the finer textured samples tend to be higher in the silt-clay fraction than in the coarser textured samples. A comparison of the data for S-6-2 (3′-6′) and S-6-2 (6′-11′) in table II, shows that the material from 6 to 11 feet is slightly higher in coarse sand and clay, the fine sand fraction lower, and the silt per cent about the same. Their curves are very similar.

Quartile measures are often used in describing and comparing sediments, and they are easily interpreted from a cumulative curve. The second quartile, or median diameter, is the average grain diameter of the sediment. The sorting coefficient, as used by Trask (1932)[68], is the extent to which the grains spread on either side of the average. It is expressed as the square root of the ratio of the diameter of the 75 per cent value (third quartile) to the diameter of the 25 percent value (first quartile). The sorting coefficient is an index of the range of conditions present in the transporting fluid; a value equal to one indicates the material consists of only one particle size.

The values of the median diameters and sorting coefficients of the detailed study samples are presented in table II. Using 0.42 mm. as the size separation of fine sand and coarse sand, all the median diameters fall within the fine sand texture group. The sorting coefficient is similar for all samples. According to Trask's classification (1932), a well sorted sediment is one having a sorting coefficient of less than 2.5. All the samples would therefore be classed as well sorted sediments.

Uniformity coefficient and effective size are terms used in expressing the general grading of soils. From Spangler (1951)[49], effective size is the maximum diameter of the smallest 10 percent by weight of the soil particles. It therefore may be taken from the cumulative curve as the point where the 10 percent line crosses the curve. Uniformity coefficient is the quotient obtained by dividing the maximum diameter of the smallest 60 percent by weight, of soil particles by the effective size. The values of the uniformity coefficients and effective sizes are shown in Table II.

Since these terms are arbitrary and serve only as an approximate means for expressing the grading of a soil, only generalities may be made. The value of the uniformity coefficient indicates how well the different particle sizes are distributed from the smallest to the largest. The larger the value, the more spread out from fine to coarse sizes and therefore a well-graded soil. Likewise, a uniformity coefficient equal to one would indicate a material in which all particles were of the same size. The sand samples would therefore be poorly graded.

The lower the value of the effective size, the higher the per cent of fine material in a sample. All the sand samples have relatively high values for effective size. The finest textured sample (S-57-4) has the lowest effective size and also the largest amount of fine material.

On a regional basis, certain trends may be seen in the median diameter and sorting coefficients. As previously mentioned, there are several different associations of the sand in the field. The sand in the east-central part of the study area is more closely associated with the loess and the streams, and in the northeastern part the sands are associated with the Iowan drift and the streams. Though there is no uniform trend of the average particle size and degree of sorting throughout the whole area, the samples from the east-central area do tend to be finer and better sorted than the northeastern area samples. These relationships are shown in figures 17 and 18. The weighted averages of the median diameter and sorting coefficients were calculated for the composite C horizon of each of the complete sections. In each of the histograms 21 out of 33 sections, or 63.6 per cent, are between the limits of 0.225 to 0.325 mm. for the median diameter and 1.25 to 1.45 for the sorting coefficients. However, only 14 of the 21 sections occur within these limits on both histograms.

The fineness of some of the east-central samples most probably reflects their association with the loess of that area. Their lower sorting coefficients also indicate these sands probably have been reworked more. The samples related to the streams and reworked little or none at all are coarser and more poorly sorted. The sand deposits found on the drift plain are derived from local accumulations of the sandy drift and tend to be intermediate in particle size and sorting to the sand deposits associated with the loess and the fluvial sands. Though this relationship may be biased due to sample site

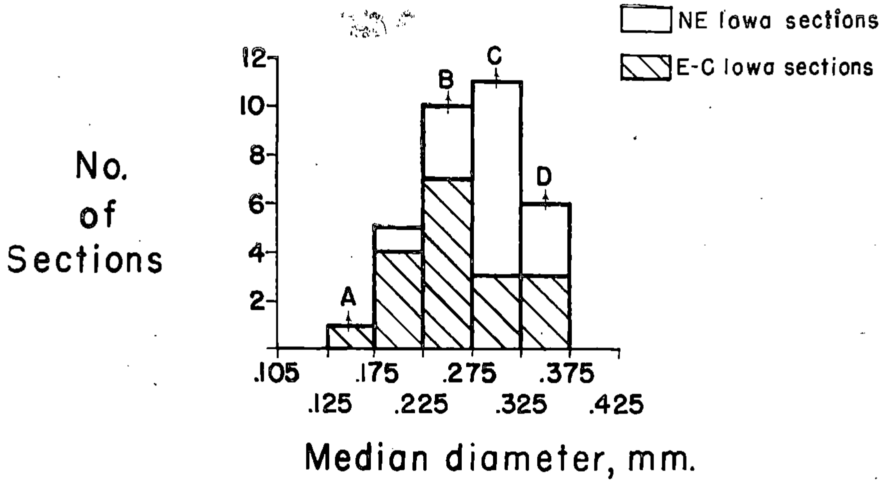


Fig. 17. Histogram showing the range of median diameters of the weighted average values of the composite C horizon part of the complete sand sections. The letters designate the median diameter of the four detailed study samples: A: S-57-4 (6′ to 13′); B: S-6-2 (3′ to 6′); C: S-28-4 (3′2″ to 9′8″); and D: S-31-1 (1′4″ to 10′4″).

selections and the varying depth of each sample, it still appears that the general relationship would hold true.

Physical Tests

Physical properties and several soil classifications are given in table III. The specific gravities of the sands are all similar. The slightly lower value for S-6-2 (6′-11′) may reflect its higher content of clay, since clay minerals have a lower specific gravity under some conditions.

The sands have no liquid limit or plastic limit, and therefore they have no plasticity index.

The engineering classification of soils is based on their textural composition and plasticity index. Using the A.A.S.H.O. (B.P.R.) system, the sand samples classify as A-3 soils with the exception of S-57-4, which has an en-

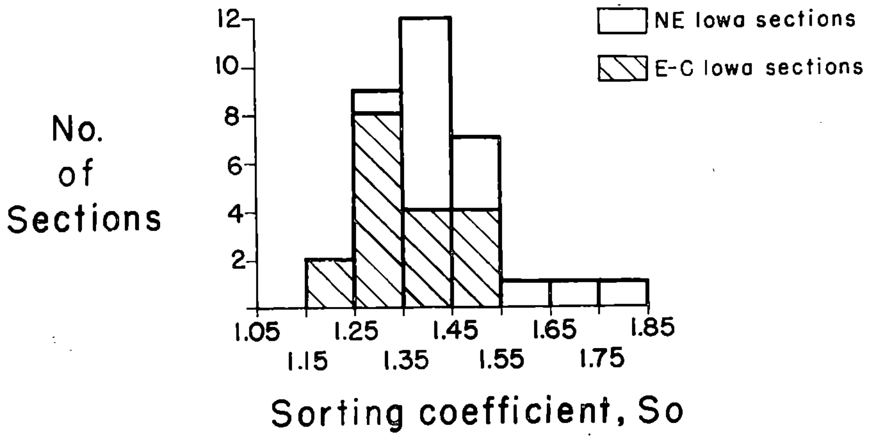


Fig. 18. Histogram showing the range of sorting coefficients of the weighted average values of the composite C horizon part of the complete sand sections.

TABLE III. PHYSICAL PROPERTIES, CLASSIFICATION, AND CHEMICAL PROPERTIES OF THE DETAILED STUDY SAMPLES.

Property	S-6-2 (3′-6′)	S-6-2 (6′-11′)	S-28-4 (3′2″-9′8″)	S-31-1 (1′4″-10′4″)	S-57-4 (6′-13′)
Specific gravity	2.66	2.64	2.66	2.65	2.66
Plasticity index	N.P.	N.P.	N.P.	N.P.	N.P.
Engineering classification	A-3	A-3	A-3	A-3	A-2-4
B.P.R. textural classification	Sand	Sand	Sand	Sand	Sand
U.S.D.A. textural clashification	Sand	Sand	Sand	Sand	Fine Sand
Standard Proctor density lbs./cu. ft	109.0	109.9	108.3	107.0	107.0
Optimum moisture, %	12.9	12.3	13.2	6.1	13.9
pH	6.7	6.5	6.4	6.8	6.9
Calcium carbonate*	0.02	0.02		0.02	0.04
Free iron*	0.24	0.42	0.57	0.20	0.17
Organic matter*	0.04	0.04	0.03	0.06	0.03

* Per cent by weight of oven-dry soil.

gineering classification of A-2-4. The reason for the different soil classification for S-57-4 is that it contains a greater amount of fine sand. According to the Bureau of Public Roads textural classification chart, the samples classify as sand. The U.S.D.A. classification using the size limits of sand 2.0 to 0.05 mm., silt 0.05 to 0.002 mm., and clay less than 0.002 mm. is given for comparison. With the exception of S-57-4, which is classified as fine sand, the U.S.D.A. and the Bureau of Public Roads textural classifications are the same.

A comparison of the textural classifications of all the samples is made using the B.P.R. and U.S.D.A. textural charts, and also using the U.S.D.A. textural chart with the engineering size gradation limits. The results are shown in table IV. The U.S.D.A. textural chart using either particle size fractions classifies more of the samples in the loamy sand group; the textural classification of the C horizons remain rather uniform throughout the three classifications.

The maximum dry densities of the sand samples are very similar. The sample with the highest clay content, S-6-2 (6′-11′) gave the highest maximum density. Optimum moisture content of S-31-1 is lower than for the other samples. This is probably due to the coarseness of the sand, which would have less surface area than the other samples. Sample S-57-4 contains the greatest amount of combined silt and clay and has the highest optimum moisture content.

Results of the permeability tests are presented in Table V. The tests were run at various CO_2 treatments and dry densities. Treatment with CO_2 removes the entrapped air in the voids and thereby gives the highest results for the coefficient of permeability.

Permeability of the sands is dependent upon their void characteristics, such as amount of voids, particle size distribution, and continuity of the void space, and is expressed as the per cent of the ration of the total volume of the voids or pores to the total volume of the soil. The coarser textured sands have the highest coefficients of permeability, and the sand with the greatest amount passing the number 200 sieve (S-57-4) has the lowest value. The great differences in the permeabilities seem to be more related to the mechanical composition than the porosities, since two sands under the same condition and at similar porosities give very different results.

Sample S-6-2 (6′-11′) contains the highest per cent clay, but in the loose condition gives a rather high permeability. This is due to the aggregation of the sand particles causing a low density. When compacted, the aggregates break down and the permeability decreases sharply.

Chemical Tests

The results of the chemical tests show that the pH of the sand is related to the carbonate content (table V). Since the sands contain only a

Table IV. Comparison of Textural Classifications of All Eastern Iowa Sand Samples.

Soil Class	U.S.B.P.R.*			U.S.D.A.†			U.S.D.A. mod.‡		
	Surface	Bands	C Horizons	Surface	Bands	C Horizons	Surface	Bands	C Horizons
Sand	38	5	99	23	4	96	31	2	94
Loamy sand	--	----	--	10	1	5	7	3	7
Sandy loam	7	----	2	2	----	----	7	----	----
Clay loam	1	----	----	----	----	----	----	----	----
Loam	----	----	----	1	----	----	1	----	----

* U.S. Bureau of Public Roads textural classification using sand 2.0 to 0.074 mm., silt 0.074 to 0.005 mm., and clay finer than 0.005 mm.

† U.S. Department of Agriculture textural classification using sand 2.0 to 0.05 mm., silt 0.05 to 0.002 mm., clay finer than 0.002 mm.

‡ U.S. Department of Agriculture textural classification using sand 2.0 to 0.74 mm., silt 0.074 to 0.005 mm., clay finer than 0.005 mm.

very small amount of carbonates, the pH is low, being slightly acidic to nearly neutral.

The free iron content compares favorably with the amounts of free iron in similar sands[21]. The S-6-2 (6′-11′) material concentrated with bands contains approximately twice as much free iron as S-6-2 (3′-6′). The higher

TABLE V. COEFFICIENTS OF PERMEABILITY OF THE SAND SAMPLES AT VARIOUS CO_2 TREATMENTS AND DRY DENSITIES.

Sample	Dry Density lb. per cu. ft.	Dry Density % of Standard Proctor Density	Porosity, percent	Coefficient of Permeability, Feet per Day
S-6-2 (3′-6′)				
No CO_2 treatment, no comp.	101.0	92.7	39.0	72.2
CO_2 treatment, no comp.	100.0	91.7	40.2	81.5
CO_2 treatment, compacted	109.9	100.8	34.3	38.6
S-6-2 (6′-11′)				
No CO_2 treatment, no comp.	95.9	87.3	41.9	87.2
CO_2 treatment, no comp.	96.1	87.4	42.1	85.1
CO_2 treatment, compacted	109.4	99.6	33.9	30.7
S-28-4 (3′2″-9′8″)				
No CO_2 treatment, no comp.	104.4	96.4	37.6	101.6
CO_2 treatment, no comp.	104.5	96.5	37.3	103.5
CO_2 treatment, compacted	108.0	99.7	34.8	67.3
S-31-1 (1′4″-10′4″)				
No CO_2 treatment, no comp.	101.4	94.8	39.2	119.5
CO_2 treatment, no comp.	100.9	94.3	39.0	144.5
CO_2 treatment, compacted	107.2	100.1	35.3	86.4
S-57-4 (6′-13′)				
No CO_2 treatment, no comp.	100.5	93.2	39.0	21.6
CO_2 treatment, no comp.	99.5	93.0	39.7	24.7
CO_2 treatment, compacted	106.9	99.9	35.8	15.9

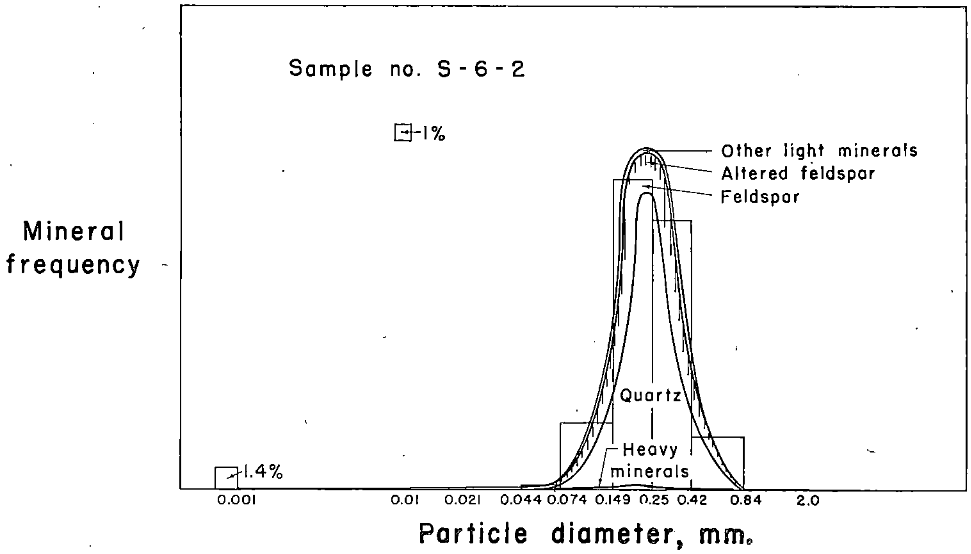


Fig. 19. Mineral composition diagram for sample S-6-2 (3′-6′).

free iron content in sample S-28-4 appears to be anomalous; however some of the free iron may have come from the iron oxide minerals, since this sample contains the highest per cent of these minerals.

Organic matter content in the sands is low and insignificant. A check analysis of the material finer than 0.044 mm. in samples S-6-2 (3′-6′) and S-31-1 found that this fraction contains 1.4 and 1.0 percent organic matter, by weight of oven-dry soil, respectively. The organic matter content therefore is in the fine size fractions.

Microscopic Determinations

Mineral composition

Mineral compositions relative to the various particle sizes are shown by frequency curves in figures 19, 20, 21, and 22. The bars of the histograms represent the various size fractions of the sample, and the area of each bar is proportional to the per cent of the whole sample in that size fraction. Each bar has been divided proportionately into the various mineral percentages in the size fraction represented, and a smooth curve drawn through the bars to produce the mineral furequency curves.

Quartz is the most abundant mineral in each fraction of each sample. Feldspars are next in abundance. Other light minerals and heavy minerals occur only in relatively minor amounts.

Light minerals

The percentages of the various light minerals is presented in Table VI. Grains listed with coatings of iron oxide or clay are those in which visible amounts of iron oxide and clay occur on the surface of the grain. These

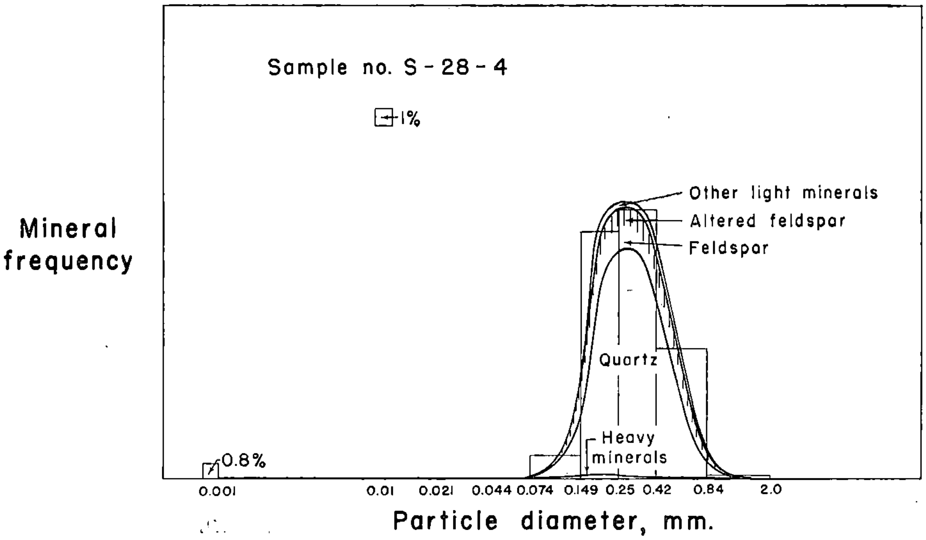


Fig. 20. Mineral composition diagram for sample S-28-4 (3'2" to 9'8").

coatings usually occur in pits, cracks, and etchings on the grain, but they very seldom cover any large surface area. Altered feldspars are those in which a visible portion of the grain is converted to some alteration product, most probably clay minerals. The alteration seems to take place along the cleavage planes within the grains.

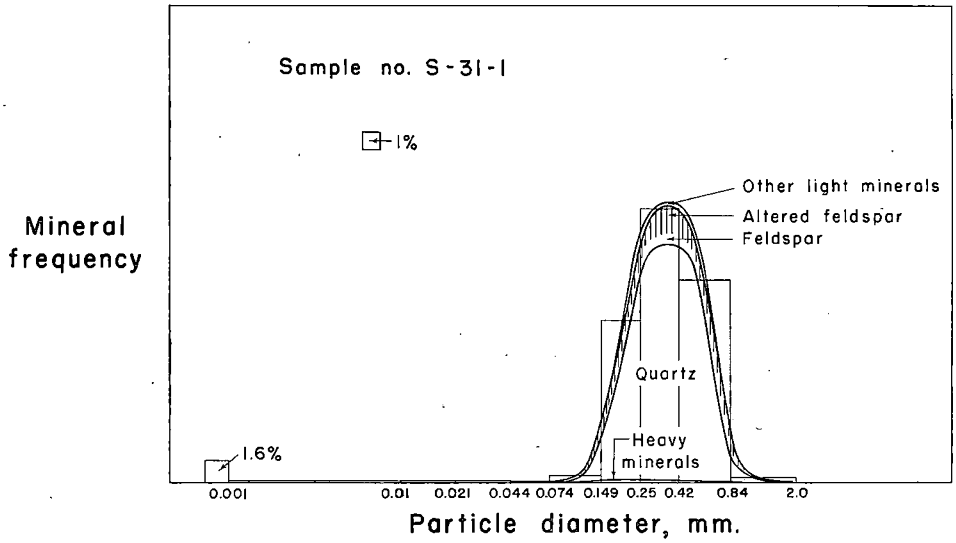


Fig. 21. Mineral composition diagram for sample S-31-1 (1'4" to 10'4").

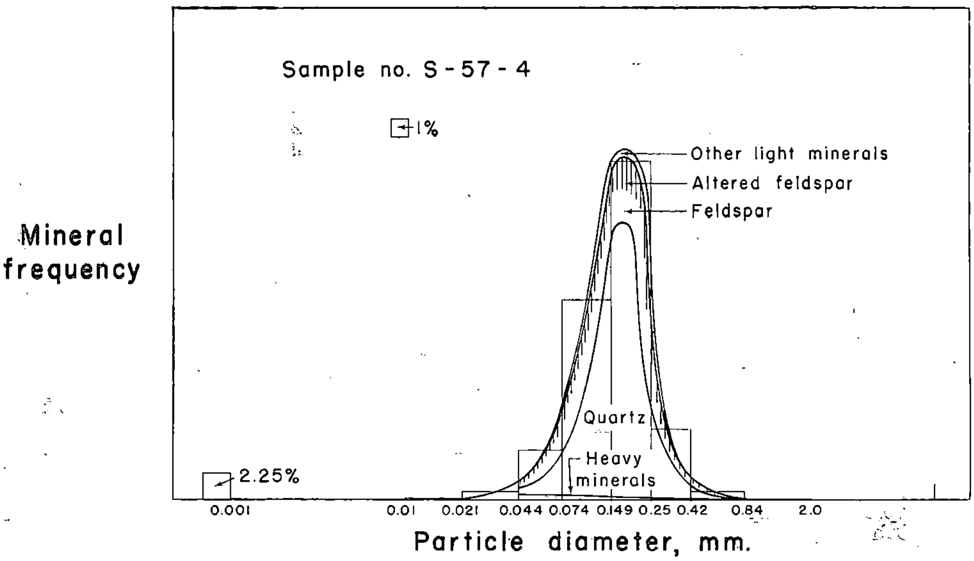


Fig. 22. Mineral composition diagram for sample S-57-4 (6' to 13').

Quartz is the most common mineral in all samples. Many of the quartz grains show stringers of bubble inclusions, indicating igneous or metamorphic origin. Many of the quartz grains also contain needlelike crystals, at times quite abundant and usually penetrating the grain in all directions. Some of the quartz grains were also observed to have strain shadows and fractures indicating that the grain has been subjected to pressures at one time. Some also contained secondary growth indicating that some of the quartz grains have undergone secondary enlargement at some time. Chert was found in minor amounts in all the samples. It would be suspected that some of the samples not studied in detail would contain higher amounts of chert, especially where the limestone bedrock is near the surface.

Feldspars are the second most common minerals in the sands. The plagioclase feldspars are more common than the potash varieties. Much of the feldspar is altered to varying degrees; the altering usually taking place along the cleavage planes. Some grains are completely or nearly completely altered. The feldspar grains are angular, irregular-shaped, and do not show any secondary enlargements. Clay, as well as some iron oxide, is also present in as irregular coatings on some of the feldspar grains.

Calcite is a very minor constituent of the sands. When calcite is present, it is found in the finer size fractions.

Rock fragment is used to designate a grain made up of more than one

TABLE VI. MINERAL COMPOSITION OF MATERIAL LARGER THAN 0.044 mm. IN THE FOUR SAND SAMPLES (PERCENT BY VOLUME OF THE WHOLE SAMPLE).

Mineral	Sample Number			
	S-6-2	S-28-4	S-31-1	S-57-4
Total light minerals	96.7	97.5	95.4	93.1
Total quartz	73.4	79.7	79.3	70.1
Clean quartz*	35.1	15.7	37.4	47.9
Fe-oxide coatings*	14.2	26.9	17.8	9.9
Clay coatings*	23.0	35.2	23.6	10.8
Chert	1.1	1.5	0.5	1.5
Total feldspar	19.9	15.0	13.4	19.8
Plagioclase	4.6	5.8	3.5	7.3
Altered plagio.	6.1	3.2	4.0	3.1
Orthoclase	1.2	0.9	0.6	3.8
Altered ortho.	1.3	1.0	0.5	0.8
Microcline	1.8	0.8	0.9	2.2
Altered micro.	0.8	0.5	0.5	0.4
Undiff. feld.	5.1	3.0	3.4	2.6
Total altered feld.	12.2	7.4	8.3	6.7
Rock fragments	3.2	2.7	2.6	2.6
Calcite	0.2	0.0	Tr	0.3
Mica	Tr	Tr	Tr	Tr
Total heavy minerals	1.0	1.8	1.1	1.9
Amphiboles	0.3	0.4	0.4	0.6
Opaque minerals	0.3	0.5	0.3	0.4
Epidote group	0.2	0.2	0.1	0.3
Others	0.2	0.7	0.3	0.6
Minus 0.044 mm. material	2.5	1.1	3.6	5.0

* After dispersion and bromoform separation.

mineral. In the sands, the rock fragments are usually quartz and feldspar or quartz and some heavy mineral.

Heavy minerals

The heavy minerals form only a small fraction of the sand, as shown in Table VI. Detailed composition of the heavy mineral fraction is given in Table VII. In each sample only the 0.044 to 0.074 mm. fraction was analyzed, because this fraction, with a slight exception in sample S-31-1, contains the highest per cent of heavy minerals. The distribution of heavy minerals according to the various size fractions is illustrated in figure 23.

Amphiboles and opaque minerals make up over half of the heavy mineral suite. The epidote group, consisting of the minerals epidote, clinozoisite, and zoisite, are the third in abundance. Garnet occurs in each sample in significant amounts. Dolomite is separated from calcite on the basis of its higher specific gravity; though some dolomite may occur in the light fraction, it cannot be distinguished from calcite. Mica is also found in very minor amounts in both the light and heavy mineral fractions; in the sands it is grouped together in the light fraction. Various other heavy minerals not shown in table VII are found in the heavy mineral suite, but occur only in minor amounts and are grouped together under miscellaneous.

Sphericity and roundess

Sphericity and roundness determinations were made of each size fraction using the permanent slides of the light minerals. Because the heavy minerals make up only a small fraction of the whole sample, they were not used. The results of the sphericity and roundness determinations are shown in figure 24. The average sphericity of the four samples in the same except that for S-57-4, which has a slightly lower average sphericity. The lower sphericity of S-57-4 is probably due to the higher per cent of silt in this

TABLE VII. COMPOSITION OF THE HEAVY MINERAL FRACTIONS OF THE FOUR SAND SAMPLES (PERCENT BY VOLUME).

Minerals	S-6-2	S-28-4	S-31-1	S-57-4
Amphiboles	29.0	23.4	32.3	32.6
Pyroxenes	2.3	5.3	7.7	3.4
Opaque minerals				
Magnetite and ilmenite	19.2	22.9	14.9	13.4
Hematite	2.8	3.5	5.1	2.7
Leucocene	1.4	0.4	0.0	3.0
Limonite	0.0	1.8	3.1	4.6
Pyrite	0.5	0.9	0.0	0.0
Unidentified	1.4	0.0	1.5	0.0
Epidote group	21.2	12.8	10.8	17.8
Garnet	7.8	7.1	5.1	3.8
Titanite	2.3	1.3	2.1	1.9
Zircon	4.2	6.6	1.5	3.4
Rutile	0.5	1.3	0.5	0.0
Dolomite	0.5	0.4	1.0	4.6
Topaz	0.5	0.4	1.0	0.0
Miscellaneous and unidentified	5.6	11.9	13.9	8.9

sample. All sphericity histograms are skewed toward the lower sphericity values, indicating the presence of a greater variety of grains less spherical than the average. Sphericity values of each of the particle size fractions are shown in figure 25. These histograms show that the larger size fractions are more spherical than the finer size fractions.

The average roundness of the four sand samples ranges from 0.52 to 0.56. Sample S-57-4 also has the lowest roundness value. Sample S-31-1, which is the coarsest textured, has the highest degree of roundness. The roundness histograms are skewed toward the higher roundness values, indicating a greater variety of grains having roundness values greater than the average roundness. The roundness values for each size fraction is shown in the histograms in figure 25. This shows that the larger fractions also have higher roundness values than the finer fractions.

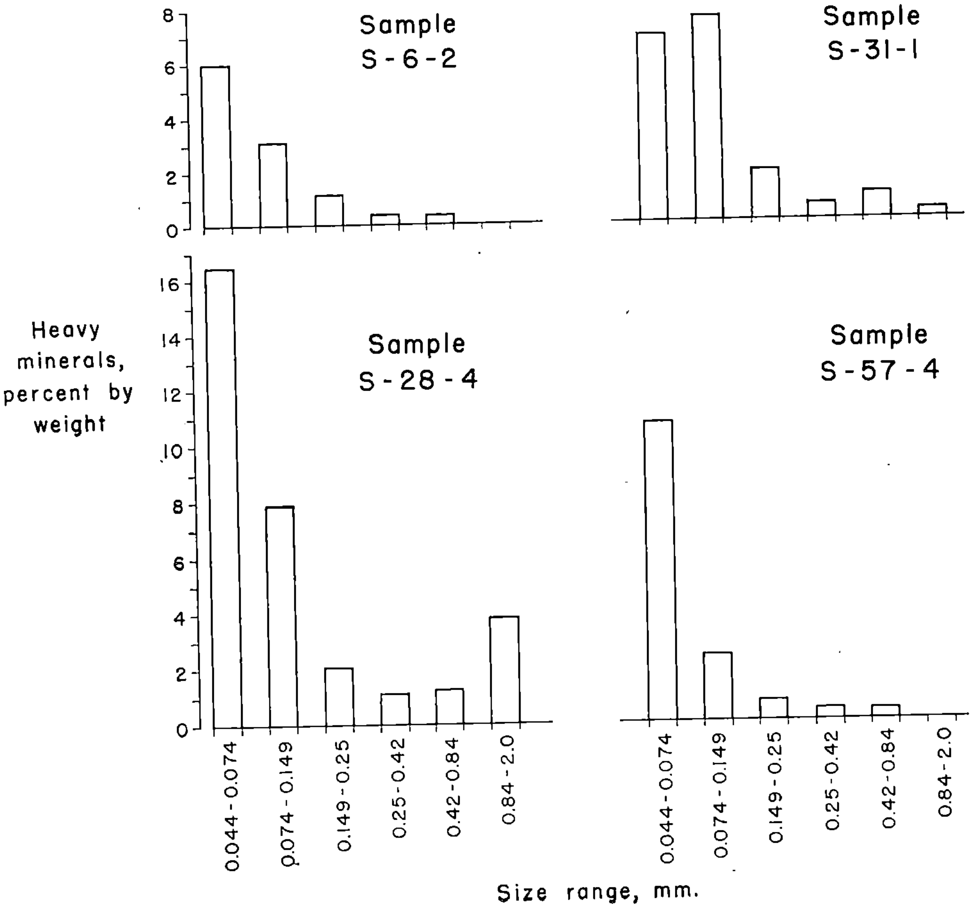


Fig. 23. Percent heavy minerals by weight in the various size fractions in each sample.

Of the individual grains, quartz is generally more spherical and has the highest roundness values. Many of the feldspar grains are fractured and broken, and therefore have lower sphericity and roundness values.

Clay Minerals

Differential thermal analysis

Differential thermal curves for the minus 0.002 mm. (2 micron) material of the four samples are shown in figure 26. The downward peaks in the

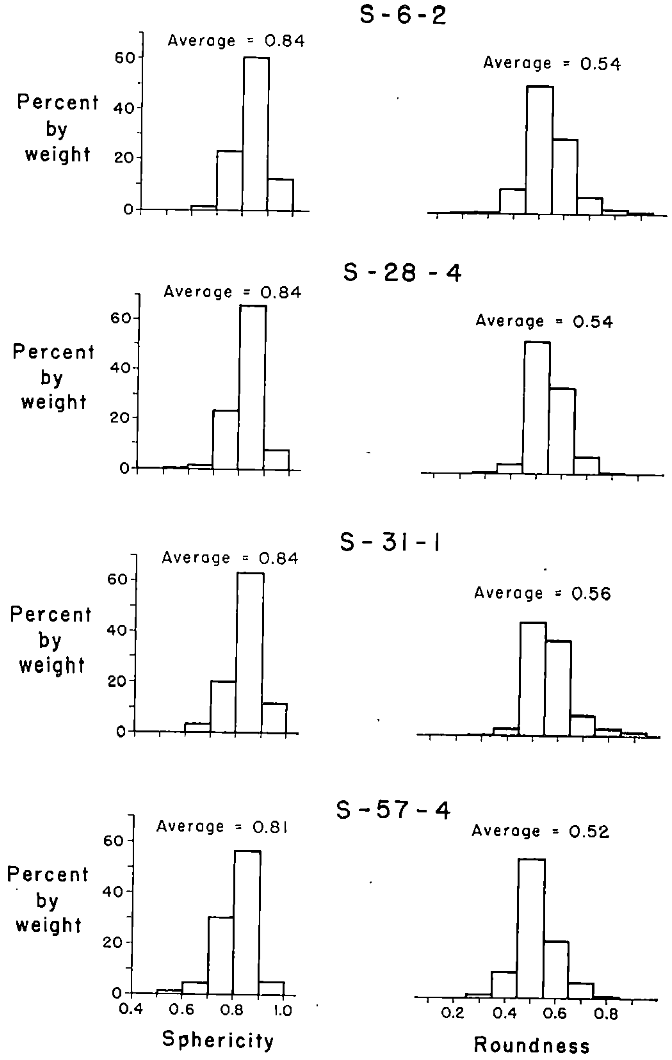


Fig. 24. Histogram showing the range in sphericity and roundness of the four detailed study samples.

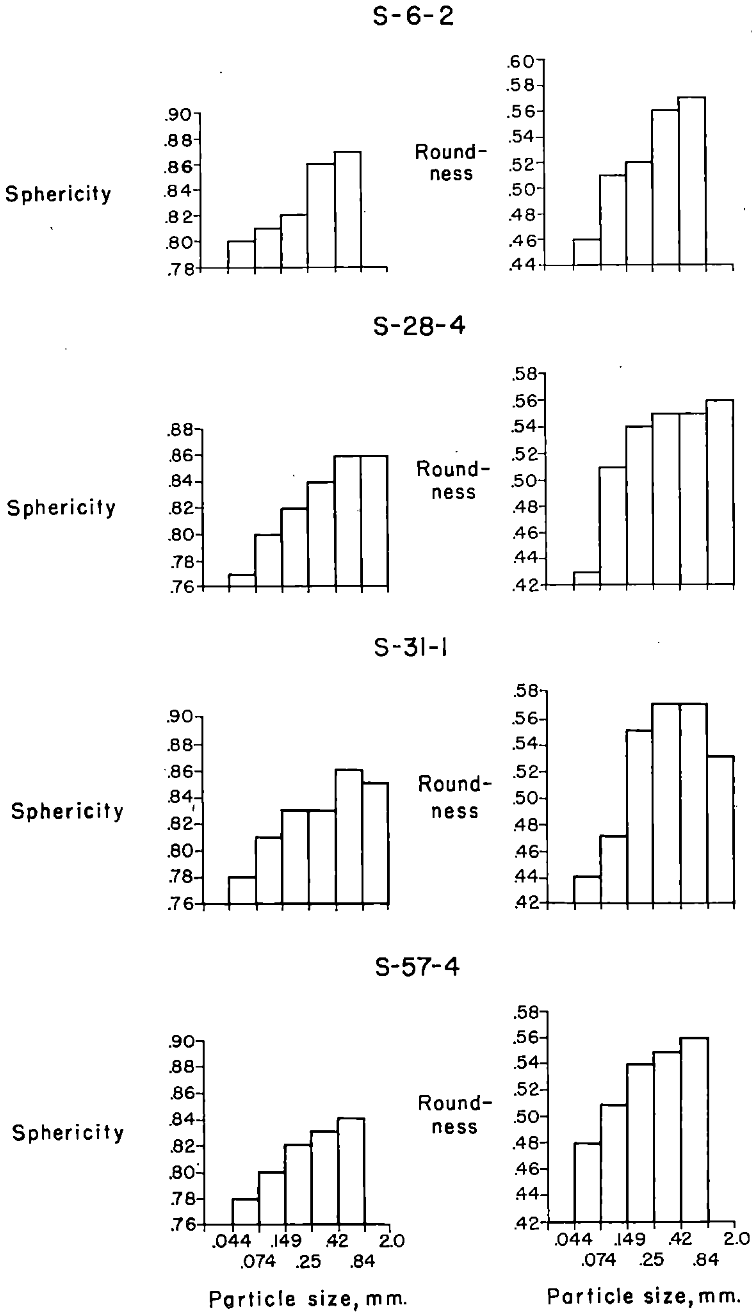


Fig. 25. Histogram showing the sphericity and roundness values for each size fraction of the four detailed study samples.

curves indicate the endothermic reactions, the upward peaks the exothermic reactions. All the curves are very similar. The general characteristics of the curves are as follows: A large endothermic peak between 100° C. and 250° C. with a small endothermic deflection at about 200° C. At slightly over 300° C. there is a small exothermic peak. A second endothermic peak occurs between 500° C. and 600° C. with a smaller endothermic reaction at about 850° C. The final reaction is exothermic at about 900° C.

The large initial endothermic peaks are the loss of adsorbed water on the clays. The small dual peak at about 200° C. is attributed to the loss of the water around the cation, which is probably calcium. Both illites and montmorillonites have characteristic initial endothermic peaks between 100° C. and 250° C. However the size of the initial peak is more suggestive of the montmorillonites.

The exothermic reaction at about 300° C. is caused by the oxidation of organic matter. It was found in the chemical analysis that most of the organic matter present in the sands is in the fine size fractions.

The endothermic reaction between 500° C. and 600° C. is attributed to the loss of OH^- structural water. The characteristic second endothermic

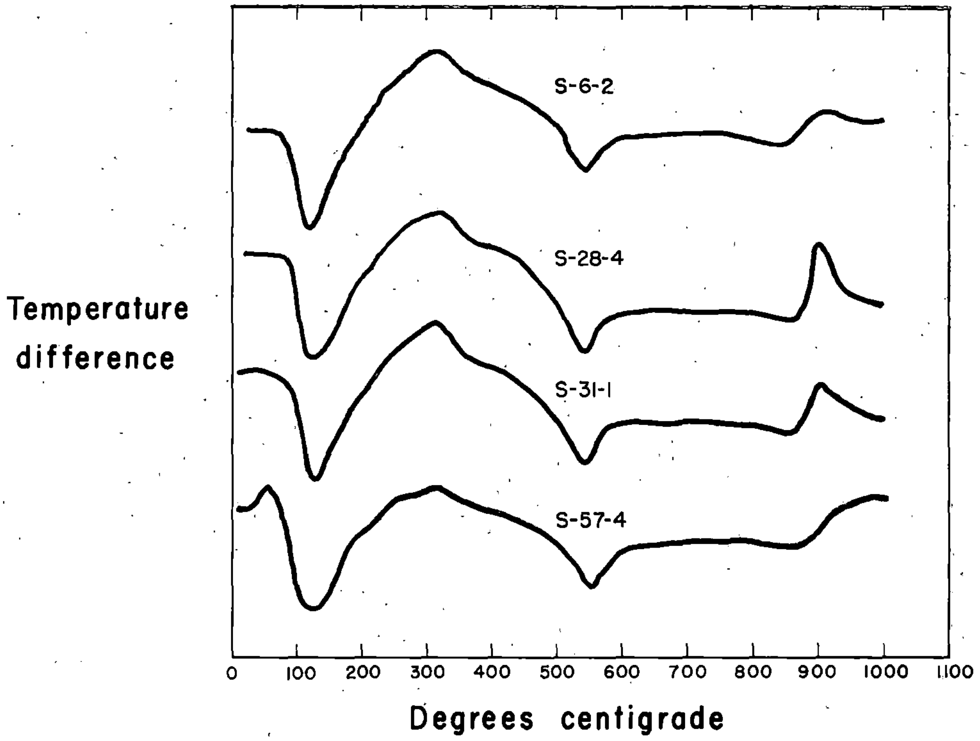


Fig.26. Differential thermal curves for the minus 2 micron clay fraction of the four detailed study samples.

peak in illites is between 500°C. and 650° C.; in montmorillonites a similar reaction takes place between 600° C. and 700° C. The 550° C. peak in the curves is therefore more characteristic of illite.

The third endothermic peak is characteristic of three-layer clay minerals and has not been found to exist in the two-layer lattice-type clay minerals. This peak is attributed to the reaction caused by the final breakdown of the lattice structure. The temperature of this final reaction can vary considerably, but the reaction usually takes place at about 850° C. and 900° C., and is followed by an exothermic reaction, the recrystallization of the material to spinel. With increased iron content this exothermic reaction takes place at slightly lower temperatures, and in samples with low iron content, the reaction takes place over 1000° C.[23] The lower temperatures for the exothermic peaks are therefore probably due to the high iron content in the clay.

To summarize the interpretation of the differential thermal curves, the type of clay mineral to be a mixture of illite and montmorillonite, with illite predominating. The presence of the montmorillonite is indicated by the relatively large adsorbed water peak. Illite is indicated by the large peak at 550° C., and a three-layer clay mineral, which both illite and montmorillonite are, is indicated by the small endothermic peak at about 850° C. Randomly interlayer mixtures of illite and montmillonite are very common and exist in a transitional series depending upon the amount of potassium ions fixed in the lattice structure. Illites are high in fixed potassium as compared with montmorillonites, but addition or removal of potassium from the structure will vary the proportion of illite to montmorillonite in the random mixed layer type of clay minerals.

Differential thermal analysis were also run on other size fractions. The material finer than 0.044 mm. was obtained by two methods; by dry sieving and by wet sieving through a number 325 sieve. The curves obtained from the minus 0.044 material by the wet sieve method are similar to the curves for the 0.002 mm. material except that the peaks are not as sharp. A small quartz peak at about 570° C. is present on the 0.044 mm. size fraction curves. The curves for the 0.044 mm. material obtained by dry sieving produce no distinct reaction peaks except for quartz. The three endothermic peaks present on the curves of the minus 0.002 mm. size and the minus 0.004 mm. size obtained by wet sieving are very minor for the minus 0.044 mm. size obtained by dry sieving. This would indicate that the clay minerals present in the sands occur as coatings. The curve for the minus 0.044 mm. dry sieve of sample S-57-4 also had a carbonate peak at about 780° C., which was not present on the other S-57-4 curves.

The curves for the whole sand samples do not indicate anything except quartz. This could be expected, since the whole samples contain only a small amount of clay-size material.

Observation of Coatings

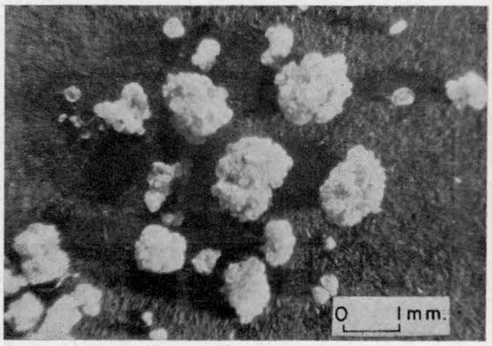
Two types of coatings are on the surface of the untreated sand grains, clay and iron oxide, with clay predominating. Clay coatings on the loess are of two distinct kinds, minute specks adhering to the grains and covering only a small surface area, and continuous coatings covering all or parts of the host grains[24]. The continuous coatings cover a larger surface area than the small specks of clay coatings. This kind of clay coatings also appears to be true in the sand.

The following is a summary of the coatings observed on the sand grains of the detailed study samples. In sample S-6-2 (3′-6′), the surface of the grains are 0 to 100 percent coated, averaging about 10 to 15 percent. Much of the clay is in the form of the minute specks. The clay that covers the grain as a continuous coating is mostly in the surface depressions.

Sample S-6-2 (6′-11′) has excessive continuous clay coatings on the grain surfaces that also fill the depressions. Over one-half of the grains have at least 75 percent of their surface covered with clay. Much of the excess clay on the grain surfaces cause the grains to aggregate (figure 27). In some the clay fills the inter-pore spaces between the grains. Iron oxide coatings are minor compared with the clay coatings and are mostly in the depressions of the grains.

About 25 percent of the surface area of the particles are coated with clay in sample S-28-4. Most of the clay is in the minute flake form. There are very little continuous coatings of clay and no aggregating of particles. Sample S-28-4 has more iron oxide coatings than the other samples. Some of the iron covers much of the individual grain surface, but most of the iron is found in the surface irregularities.

Nearly all the grains in sample S-31-1 are coated with clay, most of it being the minute flake kind. Stuck into the clay and grain surfaces are very fine silt particles, giving the grain a sugary-like appearance on the



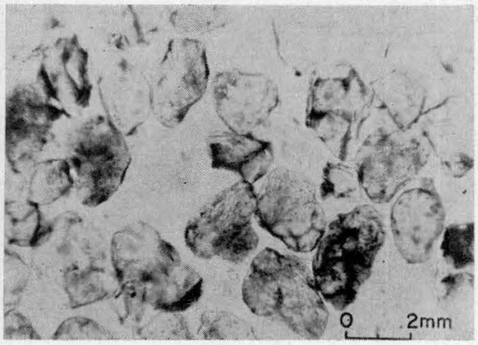


Fig. 27, at left. Aggregates in sample S-6-2 (6' to 11'). The cement is mostly clay.

Fig. 28, at right. Sand grains covered with excessive clay coatings.

surface. Approximately 20 to 25 percent of the total surface area of the sand grains are coated with clay, but nearly all the surface is covered with fine silt particles. Iron oxide coatings are minor and are mostly in the depressions.

Most of the grain surface in sample S-57-4 are clean. Only a few grains are completely covered with coatings, and only about 10 percent of the whole surface area of the sand is coated. Most of the clay is in the depressions; the same is true for the iron oxide that is present only in minor amounts. There is a small amount of aggregation of particles, the aggregates being small.

Continuous clay coatings are in sample S-6-2 (6′-11′) (figure 28). Under the polarizing microscope the coatings are visible only around the edges of the grain (figure 29). With the grain turned to extinction under crossed Nicols, the coating is seen only by the birefringence of the clay on the edges of the grain (figure 30). The clay coatings on the surface normal to the viewer are not seen because the clay minerals are birefringent only when viewed on edge.

Comparing the coatings on the uncleaned with those on cleaned sand grains, the clay and iron oxide remaining after dispersion and washing are nearly always in the depressions of the grains. The iron oxide is not as easily removed as the clay during this cleaning process. Most of the clay is removed; some of the clay other than that in the depressions remains on the surface of the grain. The clay on the surface is of the minute flake kind, and therefore it would appear that this type of clay coating is more resistant to the dispersion and washing. This is probably due to the more intimate contact of the clay particle and the grain surface, producing a better bonding force. However, these minute clay particles on the cleaned grain surfaces cover only a very small portion of the total surface area.

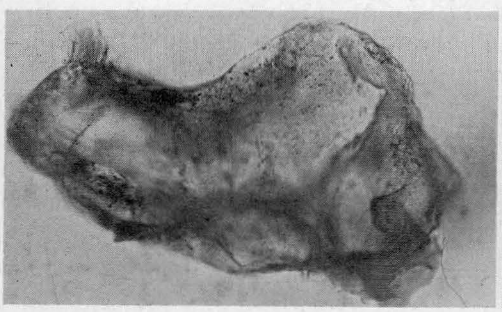


Fig. 29, at left. Photomicrograph of a sand grain in plane polarized light showing continuous clay coatings. Length of grain 0.30 mm.

Fig. 30, right. Same grain as in fig. 29 turned to extinction under crossed Nicols. Note the birefringent character of the clay coatings around the edges of the grain.

SUMMARY

The sand deposits deemed economically workable for engineering construction purposes have been mapped in eastern Iowa. There are three major associations of the sand in the field: along the margins of the Iowan drift and associated with the loess, along the major streams, and as local accumulations of the sandy drift on the Iowa till plain. A few of these deposits were sampled and their mechanical composition was determined. Most of the sand is texturally classified as fine sand, with some as coarse sand and loamy sand. In general, the finer textured sands are associated with the loess, the coarser textured sands are associated with the streams, and the sands on the Iowan till plain tend to be intermediate in texture.

Bedding features such as graded bedding and cross-bedding are common in the fluvial deposits, but are rare and indistinct in other deposits. Most striking in the sands in the field are the reddish-brown bands. These bands are found in approximately two-thirds of the sand deposits and seem to be in all types of deposits. The bands vary in thickness from a fraction of an inch up to six inches and are most commonly found at a depth of three to twelve feet from the surface. The bands differ in composition from the interband sand in that they contain higher amounts of clay and free iron.

There is no single geologic origin for the sand deposits. The sands have been classified according to their most probable mode of origin. In general, the sands associated with the loess are eolian, those associated with the streams are fluvial, and those found upon the Iowan till plain are local accumulations of the sandy drift, usually by wind action. Many of the sand deposits have been so reworked by the wind and modified by other agents that it could not be determined which geologic agent was the dominant factor in their formation. These deposits are mapped together in an unclassified category. Other deposits which did not appear to be of good engineering quality or were inaccessible in the field are mapped as undetermined quality.

Four samples representing the particle size range of all the C horizon samples were selected for detailed study. In addition, a sample containing banding material was tested for comparison of its properties with those of the non-banded sand. Quartile measures and grading values of the sand are very similar. None of the detailed samples have liquid or plastic limits reflecting the small amount of silt and clay present in the sand. They all have very similar dry densities. The permeability of the sand was tested at various CO_2 treatments and dry densities. The fine textured sands have lower permeabilities, but the porosites remain rather uniform for all textures. Sample S-6-2 (6′-11′) gives higher coefficients of permeability in the non-compacted state than sample S-6-2 (3′-6′). This is due to the aggrega-

tion of sand particles in the non-compacted S-6-2 (6′-11′) sample, giving it a lower density.

The detailed study samples contain little or no calcium carbonate and slightly acidic. Free iron contents are low; the bands contain approximately twice as much free iron as the interband areas. Sample S-28-4 contains the highest per cent of free iron, and may be in part due to its higher per cent of the iron oxide minerals. The organic matter contents are negligible.

Mineral analysis of the four samples show quartz to be the most abundant mineral and feldspars next in amount. Plagioclase feldspars predominate over the potash feldspars. The feldspars are generally weathered and altered to some degree; sample S-57-4 contains the least amount of altered feldspar. Accessory light minerals and heavy minerals make up only a small per cent of the total sample. Heavy mineral contents range from 1.0 to 1.9 percent by weight of whole sample; the smaller size fractions are higher in the heavy minerals percentages.

All samples show similar values for sphericity and roundness; the finer textured sand (S-57-4) has the low values in both sphericity and roundness. In each sample, the larger size fractions are more spherical and rounded than the small size fraction.

The clay content in the sands is present primarily as coatings on the grain surfaces. The type of clays is determined as a random mixed-layer type clay mineral consisting of illite and montmorillonite, with illite predominating. The clay occurs as two types of coatings: as minute flakes covering only a small surface area, and as continuous coatings covering parts or all of the grain surfaces. The clay also is present in the depressions of the grain. Sample S-6-2 (6′-11′) contains the most clay coatings; the clay covers the grain surface in excess causing aggregation of particles. Sample S-57-4 has the least amount of clay coated grains. Other evidence that the clay occurs mostly as coatings was found on the differential thermal curves for the minus 0.044 size fraction obtained by wet and dry sieve methods. Only small reaction peaks were obtained from the material obtained by dry sieving.

Iron oxide is also present as coatings. Samples S-6-2 (6′-11′) and S-28-4 contain the most iron oxide coatings, but the iron is still minor compared with the amount of clay coatings. Iron coatings are more resistant than clay coatings when the samples are dispersed and washed. The clay remaining after cleaning is present in the depressions and as minute flakes adhering to the surface; iron oxide remains both on the surface and in the depressions.

Experiments were run to determine if the banding phenomena in the sand could be duplicated in the laboratory. Tubes of sand were filled with S-6-2 (3′-6′) sand and leached with distilled water and with distilled water made acidic by bubbling CO_2 into the water. Bands formed in both of the sand columns; but in each the banding appeared to take place in fine textured layers due to segregation of particles during loading.

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APPENDIX A

Occurrence and Formation of Bands

Although this is not a study on the bands rich in clay and iron that occur in the sands, their prominence makes it necessary to review briefly their occurrence and possible modes of formation. They are also important from the engineering point of view, for their presence may influence the use of the sand. An estimate of their frequency in the sands in eastern Iowa is that they occur in 60 to 70 percent of the deposits. Folks[21] also found this to be true.

Smith *et al.*[47] considered the bands in the Thurman sand as the B horizon formed by the normal soil forming processes. Folks[21] also called the bands B horizons and designated them as B_{ir} in the profile descriptions. Another report of bands formed in sand is that of Cooper[19] in his study of some sand deposits in Minnesota. He also classified the bands as B horizons.

Lutz[31] reported layers of fine textured material in sand dunes of Cape Cod, Massachusetts, and near Glen Haven, Michigan. Though these layers contained a higher percent of fine material, he did not report any concentration of iron oxide. However, charcoal and wood fragments were present in these layers, and he therefore called them buried soil layers. Such materials have not as yet been reported in the bands in Iowa. It would therefore seem that the layers observed by Lutz and the bands in the eastern Iowa sands are not of the same nature.

Other features reported appear to be similar to the bands of concretionary material. Narel[34] described a heath podzol profile from the Netherlands which contained a thin iron hardpan at a depth of about 25 cm. He found the pan to be rich in free silicic acid and amorphous sesquioxides. His interpretation was that the iron hardpan was of fossil origin and due to differential weathering of the minerals in the sand.

Reifenberg[39] in discussing the soils of Palestine, described a compact, impermeable pan layer, concretionary in form and often found at a slight depth below the surface in the red sandy soils and in sand dunes. The layers are zones of clay and sesquioxide concretions attaining a thickness of one meter. No satisfactory explanation was given for the formation of these layers.

Willcox[77] described some thin iron rich bands in the Redbank sands of New Jersey. In the same formation are peculiar iron concretions, assuming a hollow cylinder shape, varying in length up to 20 feet and ranging in diameter from ¼ inch to nearly 1 foot. These tubeshaped concretions also formed in polychambered forms. The concretions nearly always occupied a horizontal position with their long axes parallel to the strike of the formation. No clay accumulation in the bands or concretions were reported, only a concentration of iron as evidenced by the color. The iron was considered to have moved into the areas of concentration from the surrounding sand by diffusion.

Beater[5] reported layers of iron concretions in recent sand in Natal, South Africa. The concretions were of irregular shape, high in iron, but not necessarily high in clay. He believed the concretions to be derived from the processes forming the genetic soil profile.

Several different possible modes for the formation of the bands have been expressed. Folks[21] gives an excellent review of these together with some of the different points of view on the movement and immobilization of iron in the soil. One of the most common explanations is that iron flocculates in the clay, and thereby blocks the pore spaces. Once this has started, additional iron and clay will accumulate. Another hypothesis is that the bands represent the interface between an iron saturated water in the sand and the aerated sand. Upon remaining at a constant level for long periods of time, the iron becomes oxidized upon aeration and coats the grains. Still another possibility is that the bands are formed by the mechanism of a periodic precipitation similar to the Liesengang phenomenon described by Hedges, (1932). That the bands are the result of deposition, either wholly or in part, is also a possibility. There undoubtedly have been and are other possible modes of band formation, but at the present time these seem to be the most favorable explanation.

Laboratory Study on the Formation of Bands

Folks[21] made a study on the laboratory formation of bands using various methods to move and precipitate the iron and clay in the sand. He concluded that the most logical mechanism for the band formation is some form of periodic precipitation. In his experiment, one hundredth normal oxalic acid was used to move the iron in the sand, passing the acid through a one inch sand column at about 1½ milliliters per minute for one week. At the end of this time 2 to 3 millimeter bands were present in the lower end of the sand column, and the upper part of the sand was cemented. A condition essential for the movement of iron is high acidity. The conclusion was that the depth of the banding was dependent on the concentration of iron and oxalate. The bands formed when the critical concentration of the oxalic acid was reduced and the iron could no longer be carried in the complexed form. When this took place, the iron was precipitated, beginning the formation of the band. Folks also believed that the iron bands could form independently of silicate clay.

In an attempt to duplicate the band formation in the sand in the laboratory, several experiments were run using glass tubes 2 inches in inside diameter and about 4 feet long. It was found that filling the tube by pouring the sand in from the top and letting it fall the whole distance allowed segregation of the fine and coarse particles. The segregation of particles deposits the sand in the tube in a series of layers, visible only upon close inspection. However, upon wetting the sand, the layers concentrated with the finer particles appeared like the bands. This is probably due to the coloration effect, the color showing up more in the finer size fractions. Since it is not known how Folks filled his tubes with sand, it is not known if segregation of particle sizes could be responsible for any of the bands he produced.

In two other tubes, sand from S-6-2 (3′-6′) was loaded into the tube so the material wouldn't fall as far. Minor amount of segregation of particles did take place, but upon wetting of the material, they did not show up as bands. The upper 6 inches or so of the sand was a mixture of the S-6-2 (3′-6′) sand and banding material higher in clay and iron content. In one tube, distilled water charged with carbon dioxide percolated through the sand for ten days. The CO_2 was used to make the water slightly acid, the pH of the water ranging from 4.9 to 5.4. During this time there was no visible formation of bands. But when the water drained and the sand dried, 2 to 3 mm. bands were present throughout the sand column, even in the upper layer higher in iron and clay. It appears that the banding takes place where the sand is finer textured. There is evidence for some movement of iron and clay, because the upper sand material had lost its fine particles and much of its iron oxide coloring. However it was not determined how far the iron and clay moved.

The other tube was also loaded with the same material by the same method to avoid excessive segregation. To check if the movement of the clay and iron was mechanical, distilled water alone was percolated through the tube for about two weeks. After this time, thin banding was present throughout the sand column, and the bands appeared to be present in the layers containing the finer material. There was also evidence that some of the iron and clay had moved down from the top (figures 31, 32).

Because the banding appears to occur in the finer textured layers, a check of the available field and particle size data was made to determine if the bands occurred in finer textured layers in the field. The minus 0.074 mm. material was subtracted from the sand fraction to determine if the sand texture in the bands was finer. In some cases this is true, but is not consistent for all the bands and interband layers. A more detailed study of this would have to be done before any definite conclusions could be drawn.

The possibility for the finer textured layers to form the bands was also tried by Filatov[20]. He passed solutions of iron hydroxide through sand columns of quartz sand with intermediate thin layers of 0.05 to 0.001 mm. quartz. He found that only the layers of fine quartz became colored with iron. This is probably due to the higher retentive power of the fine textured material because of the lower permeability through these layers and the higher specific surface area. This may be true for the banding found in the laboratory experiments.

The only banding that can conclusively be attributed to a true periodic precipitation phenomenon is one reported by Vallentyne (1955). He found that red bands formed in a reduced mud rich in iron when the mud was exposed to the air at room temperature. The bands were truly periodic in both position and time of formation, the same as those formed by Liesegang[25]. He believed the cause of the precipitation of the iron to be due to the forming of ferric hydroxide on the diffusion of O_2 in the mud or the influence of micro-organisms. A phenomenon such as this does not seem plausible in coarser textured material.

From the available evidence, there appear to be several possible expla-

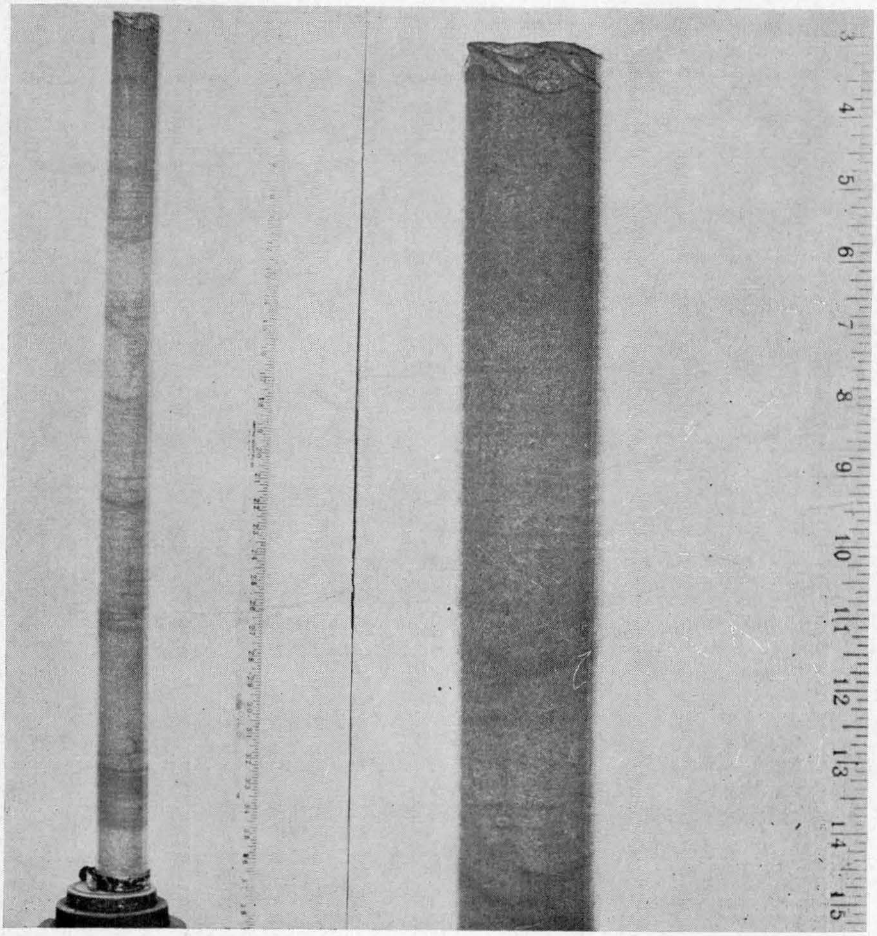

Fig. 31, at left. Bands as they occurred after ten days of leaching with distilled water made acidic by bubbling CO_2 into the water.

Fig. 32, right. Close-up of the upper part of the sand column in fig. 31.

nations for the formation of bands in the sands. Because the bands occur in different forms, as described under field description, it is also possible that several different modes of formation may be responsible for the banding. However, there is not enough evidence available to support any definite mode for their formation.

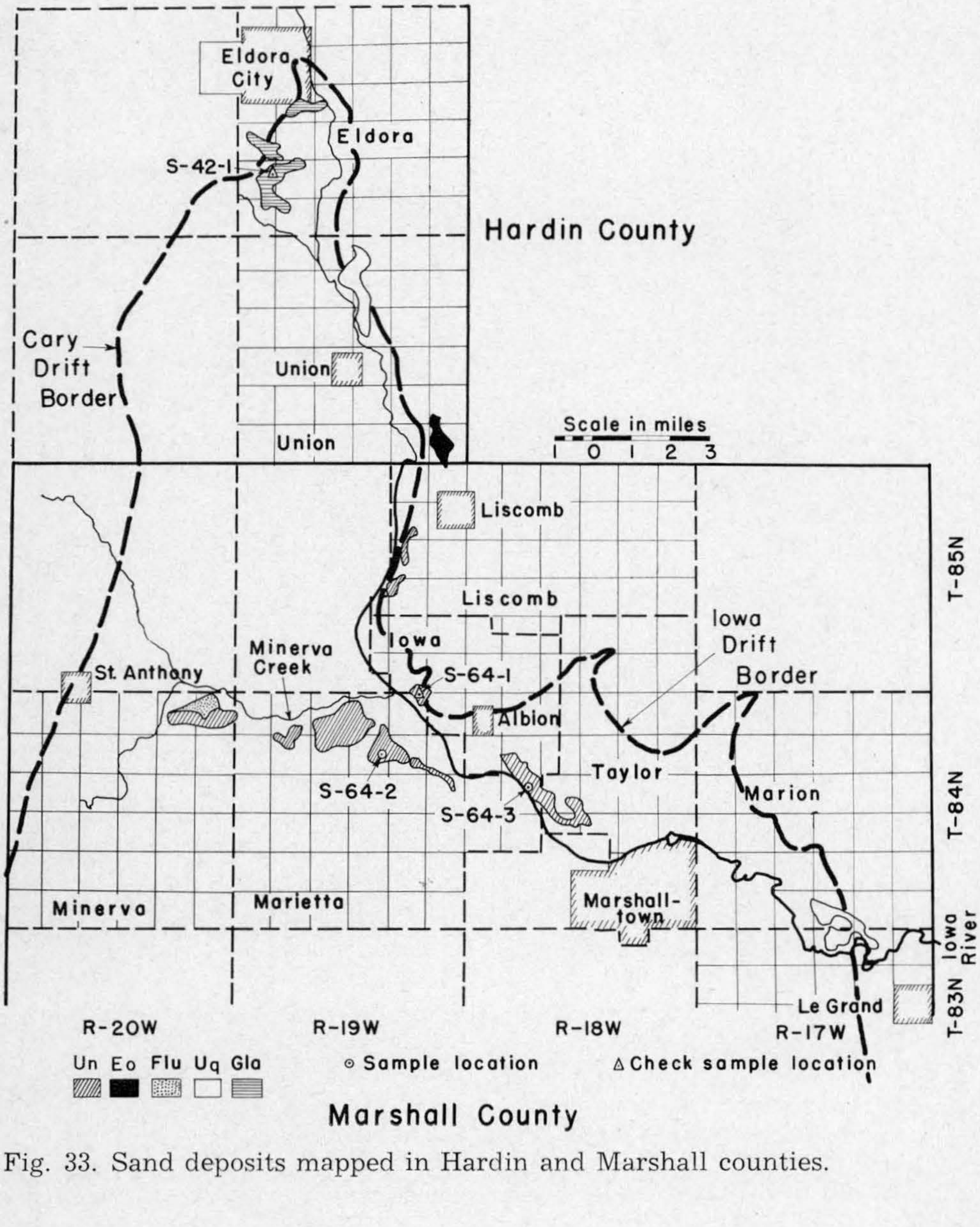

Fig. 33. Sand deposits mapped in Hardin and Marshall counties.

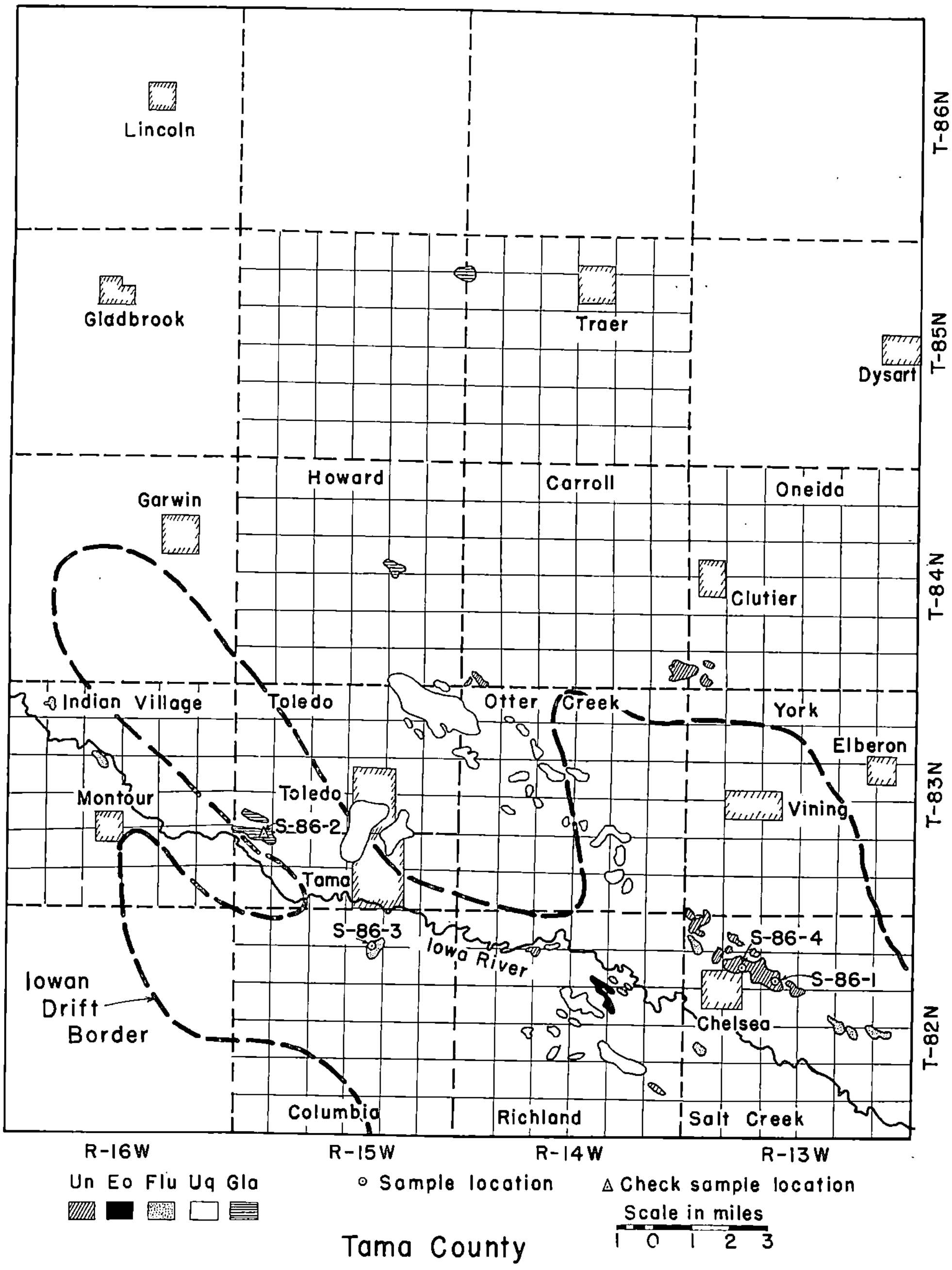

Fig. 34. Sand deposits mapped in Tama County.

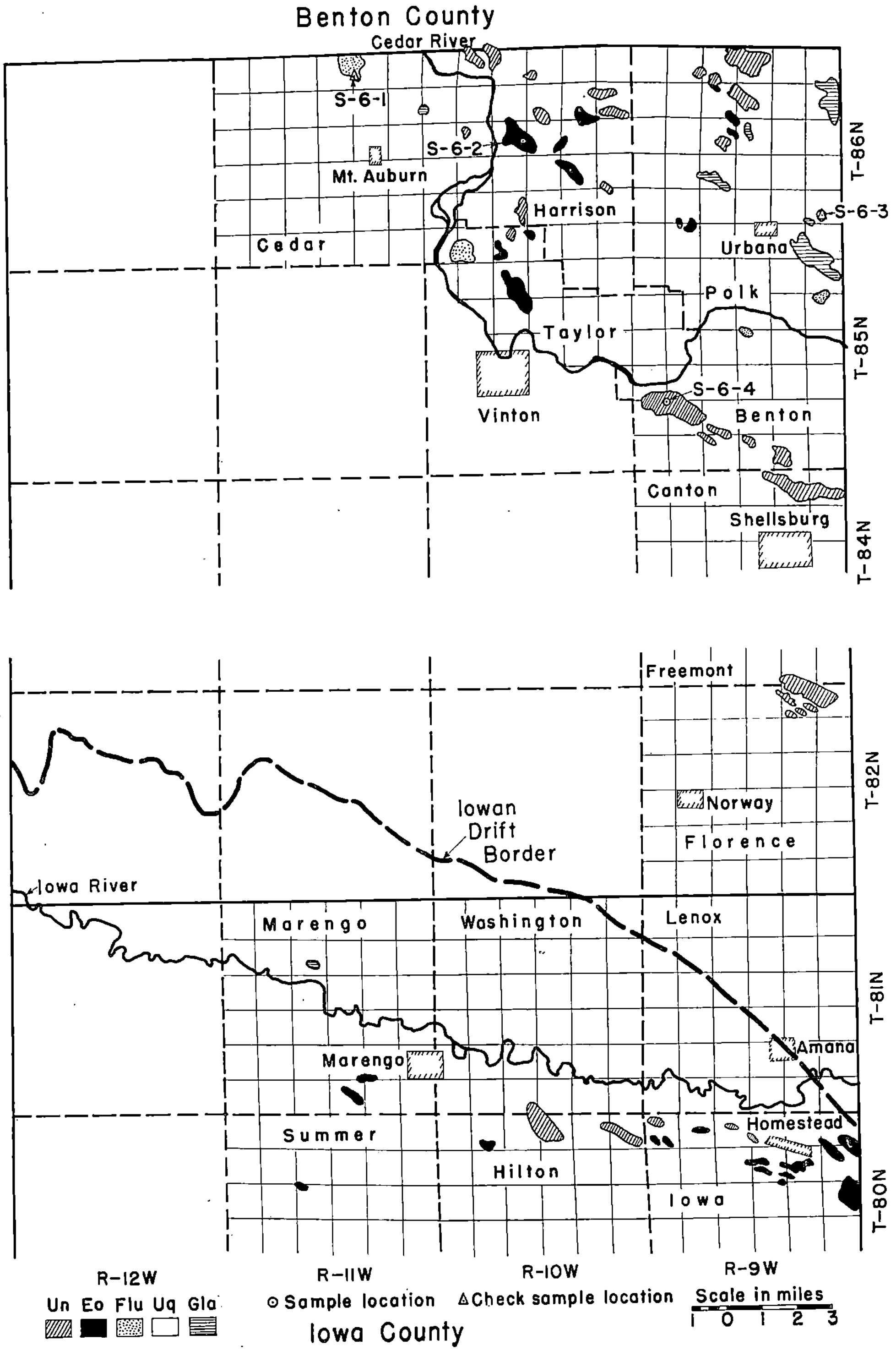

Fig. 35. Sand deposits mapped in Benton and Iowa counties.

APPENDIX B

County Sand Location Maps

One of the objectives of the present study was to determine the occurrence and distribution of fine-grained sands in eastern Iowa which are economically workable for engineering purposes. A study such as this, therefore, would not be complete unless these sand deposits are located on maps that can be easily referred to in the future. This is especially

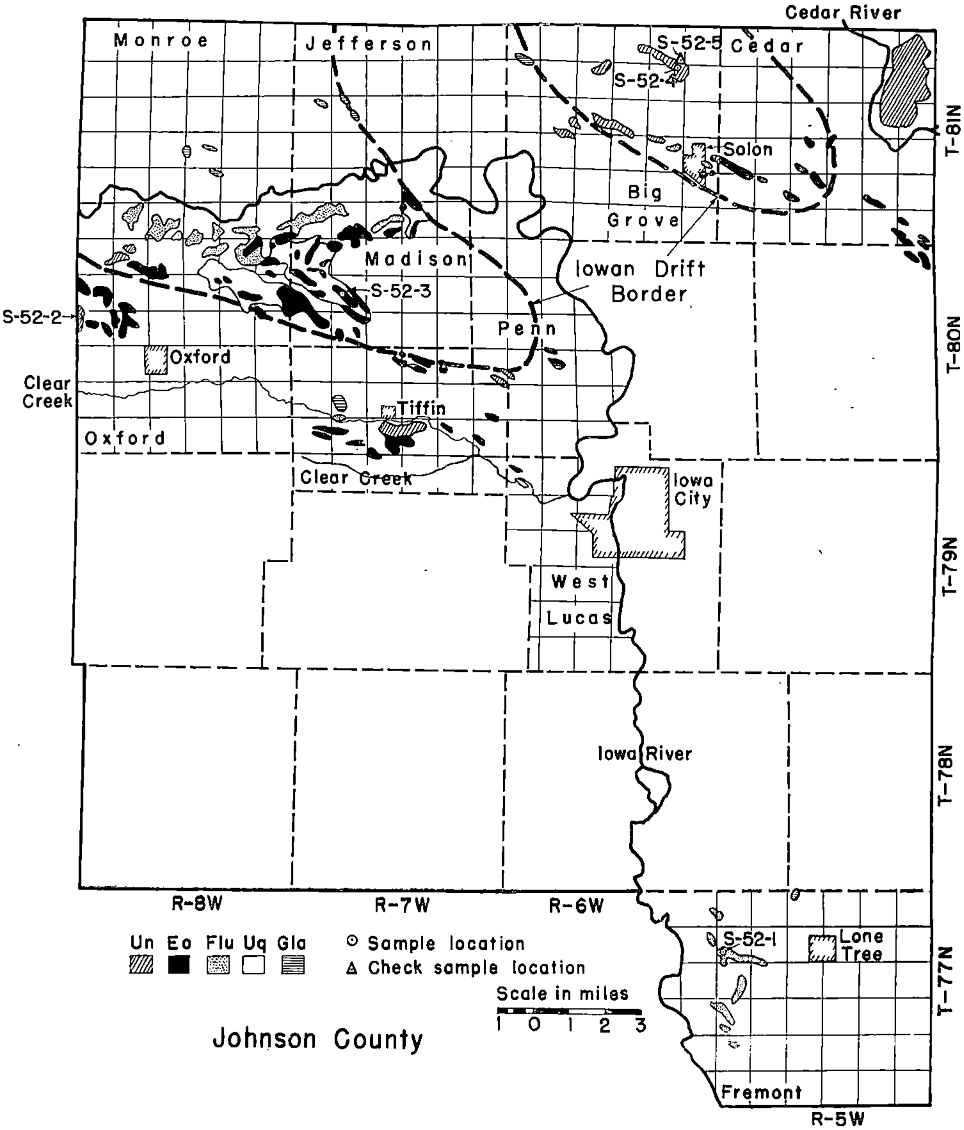

Fig. 36. Sand deposits mapped in Johnson County.

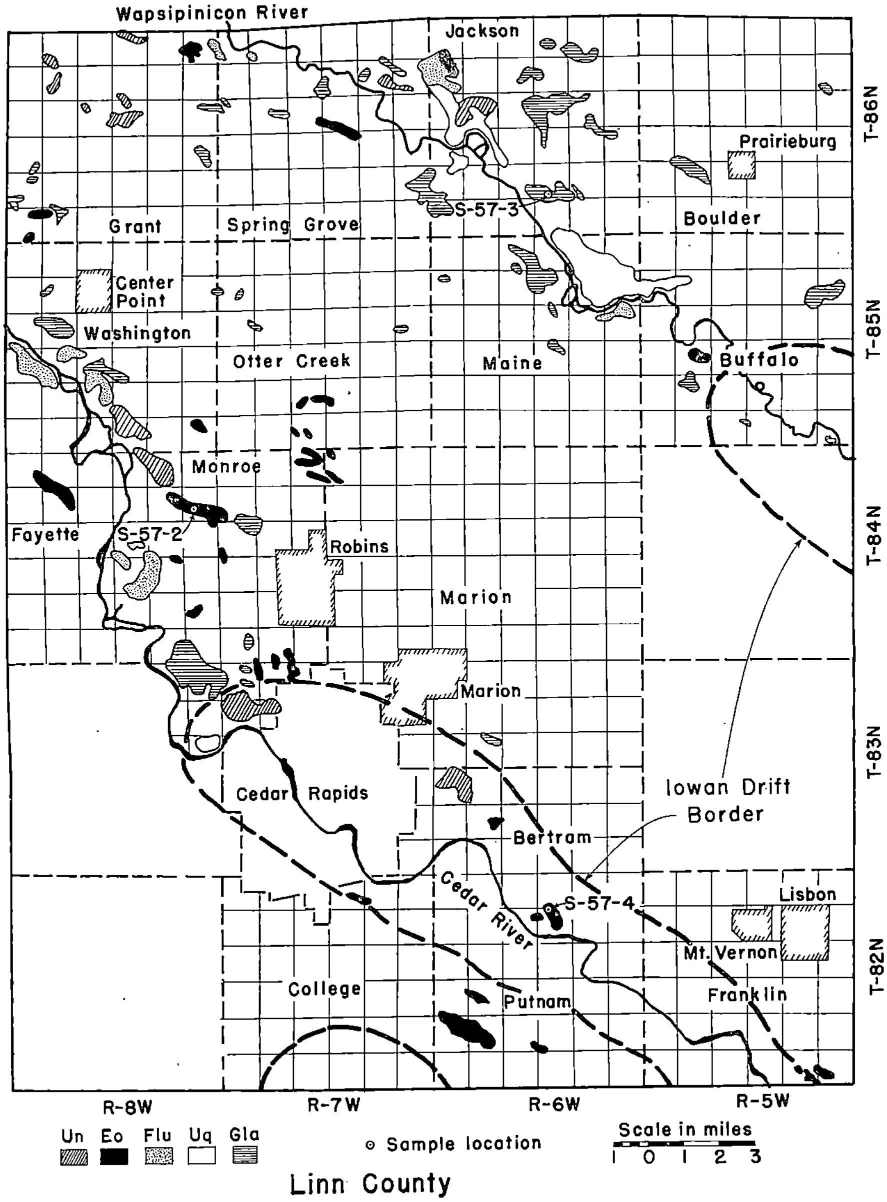

Fig. 37. Sand deposits mapped in Linn County.

important from the engineering point of view, for the sand needed for construction will already be located and additional time will not have to be spent in search for these materials.

The maps (figures 33 to 44) show the location of the sand deposits studied in each of the eastern Iowa counties. The deposits are classified according to their most probable mode of origin (see the section herein on "origin and classification", pages 179 ff).

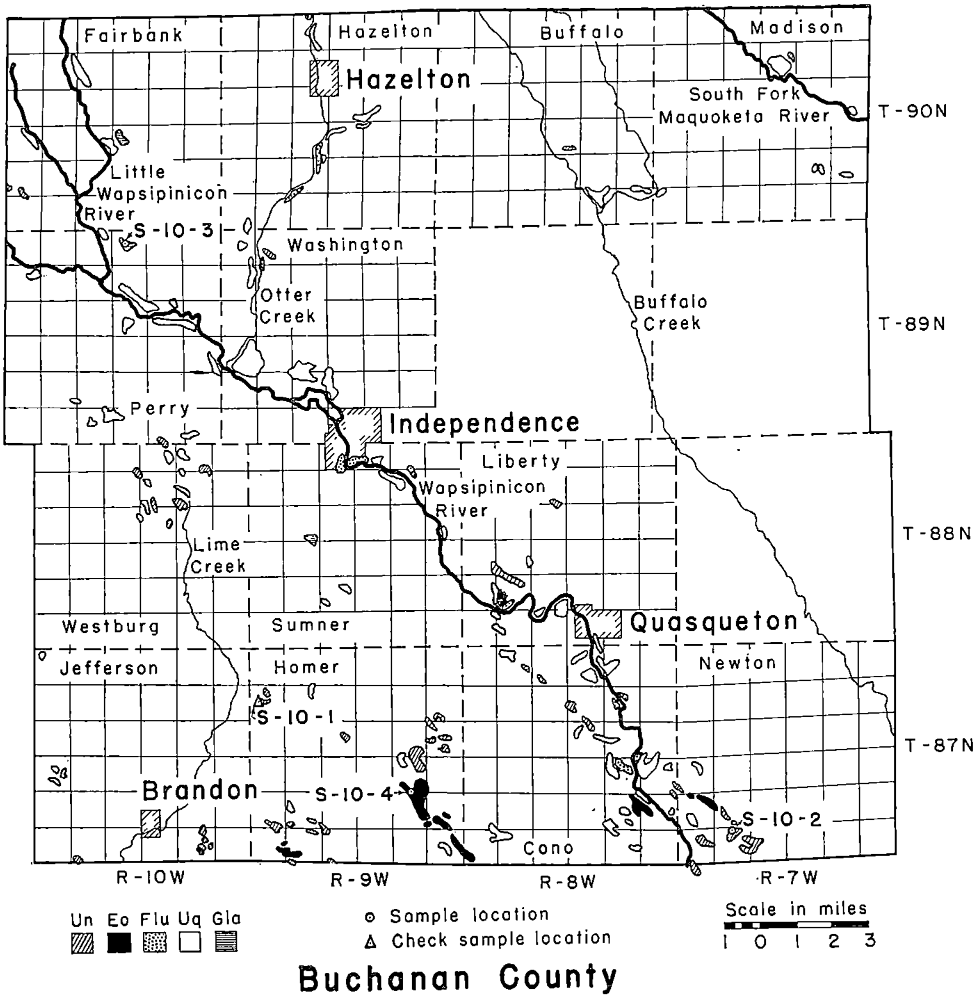

Fig. 38. Sand deposits mapped in Buchanan County.

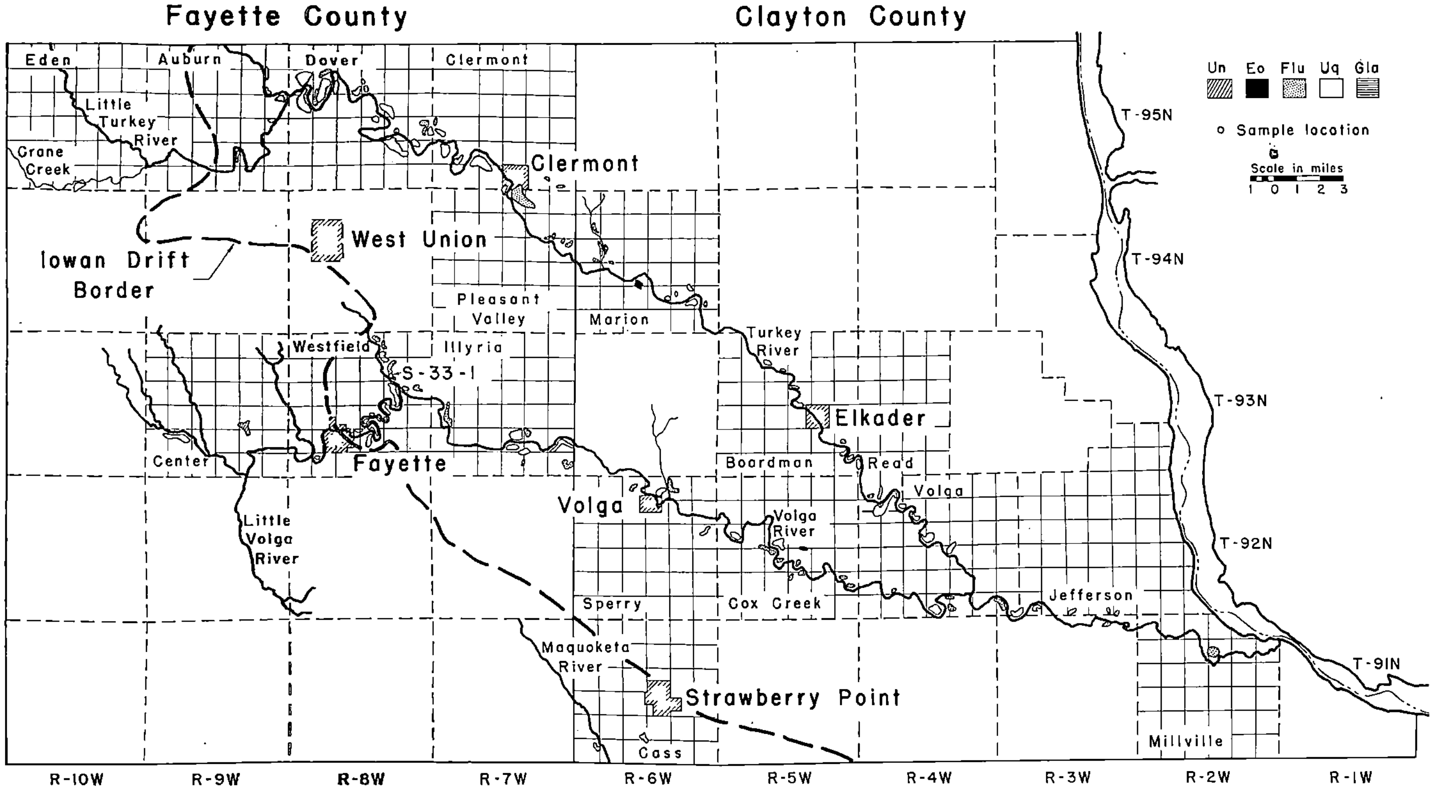

Fig. 39. Sand deposits mapped in Clayton and Fayette counties.

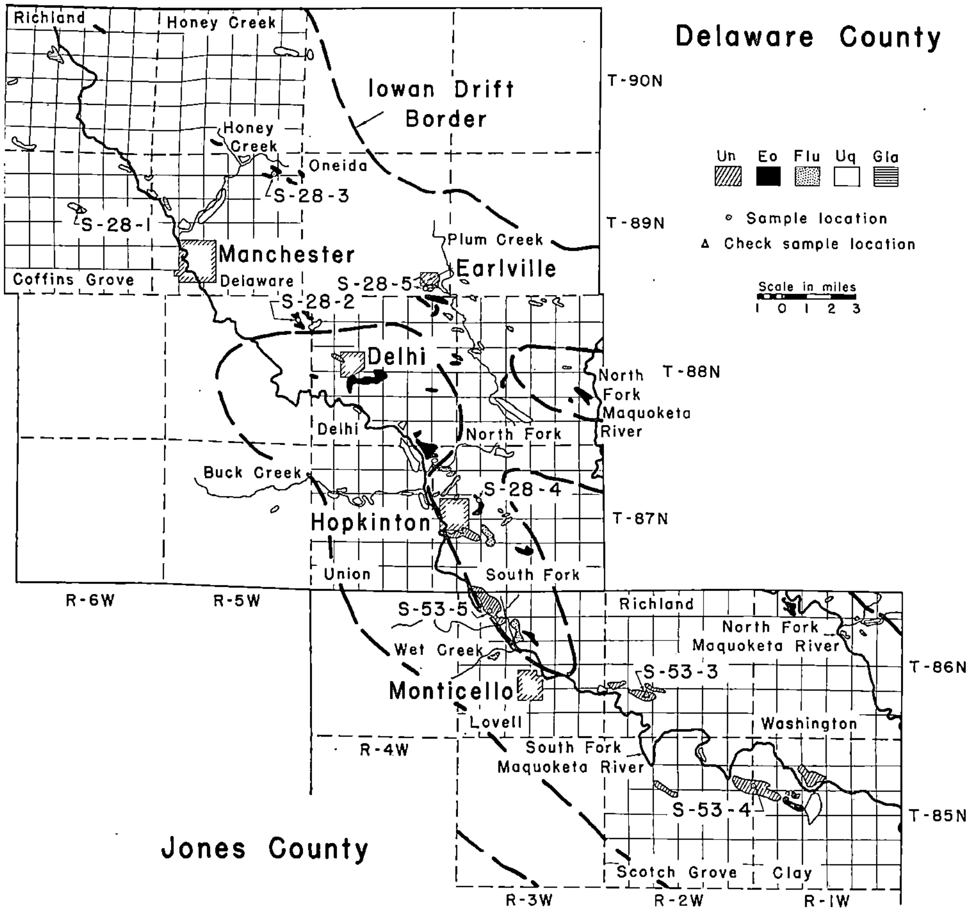

Fig. 40. Sand deposits mapped in Delaware and the northern part of Jones County.

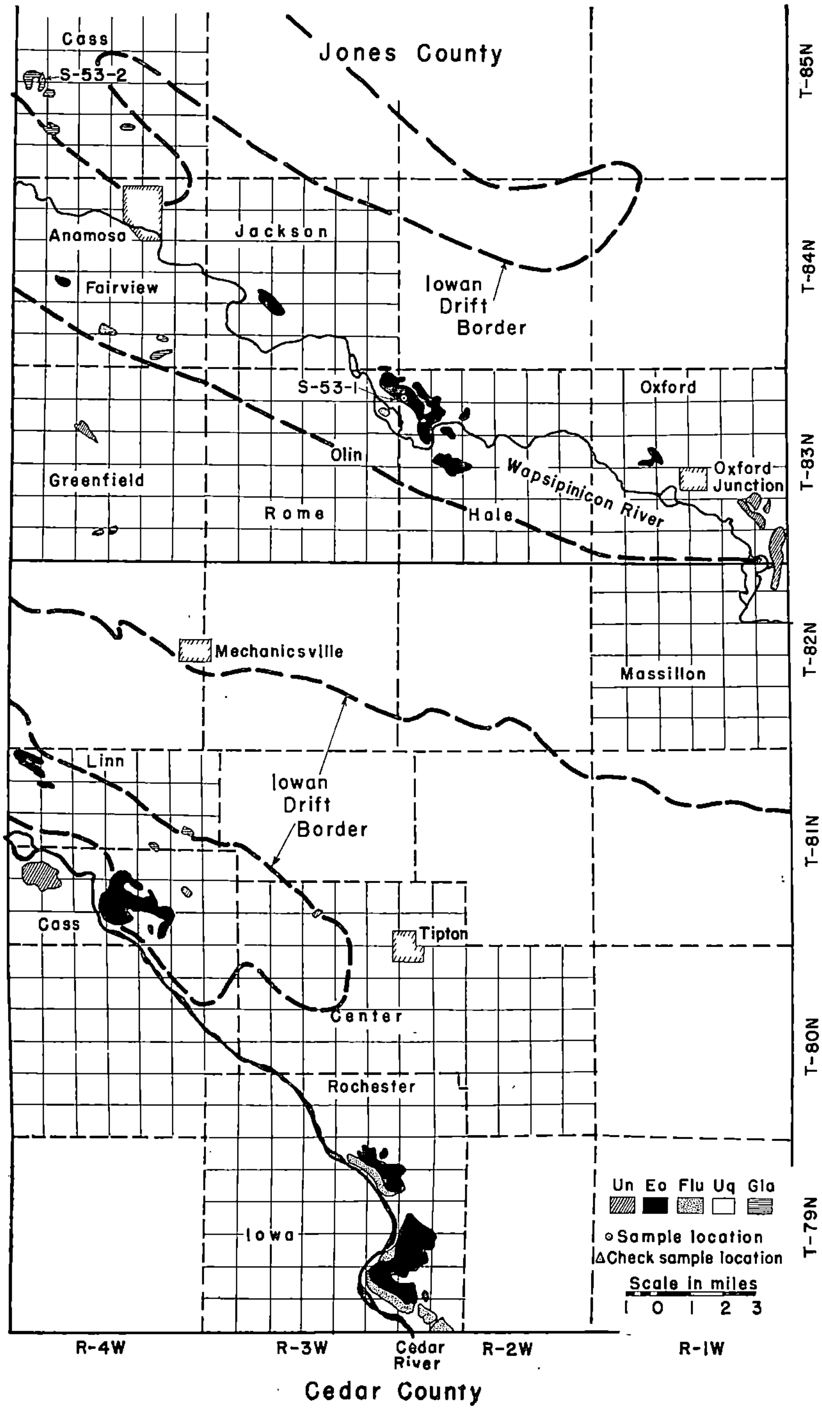

Fig. 41. Sand deposits mapped in Cedar and the southern part of Jones County.

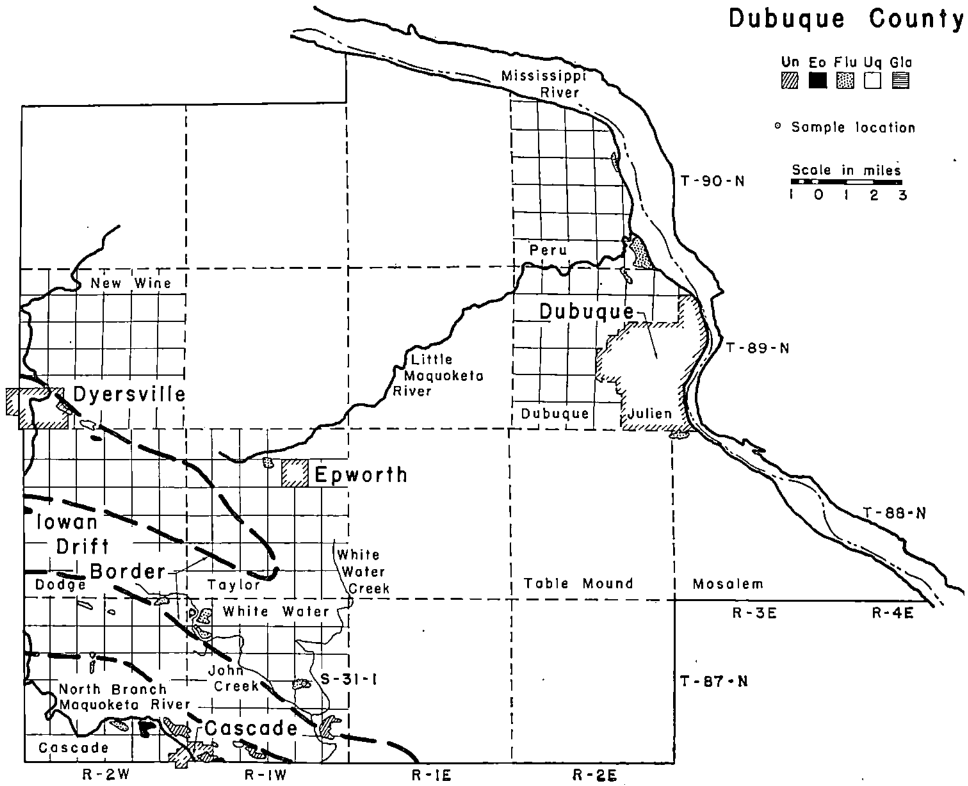

Fig. 42. Sand deposits mapped in Dubuque County.

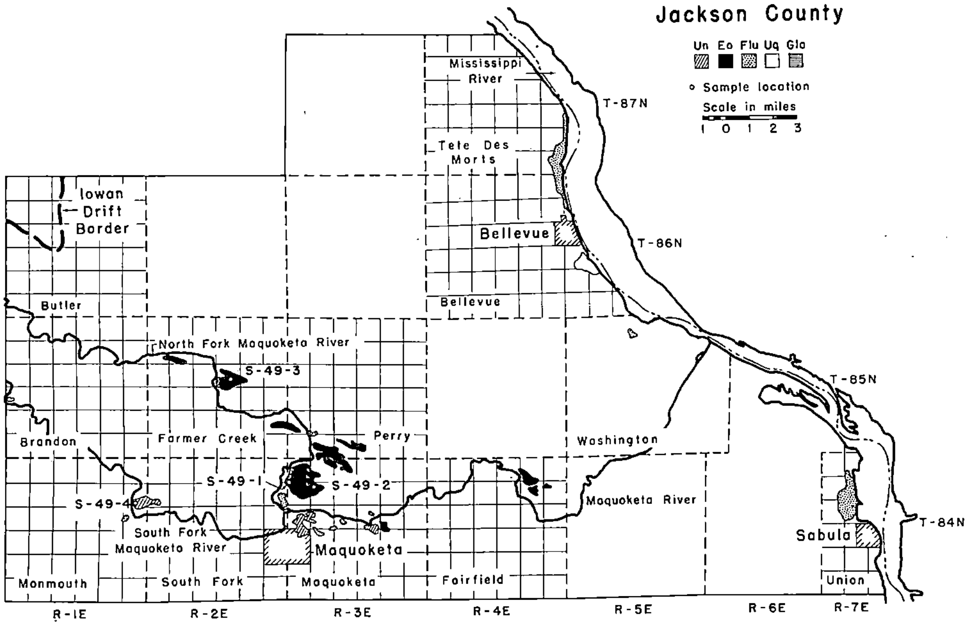

Fig. 43. Sand deposits mapped in Jackson County.

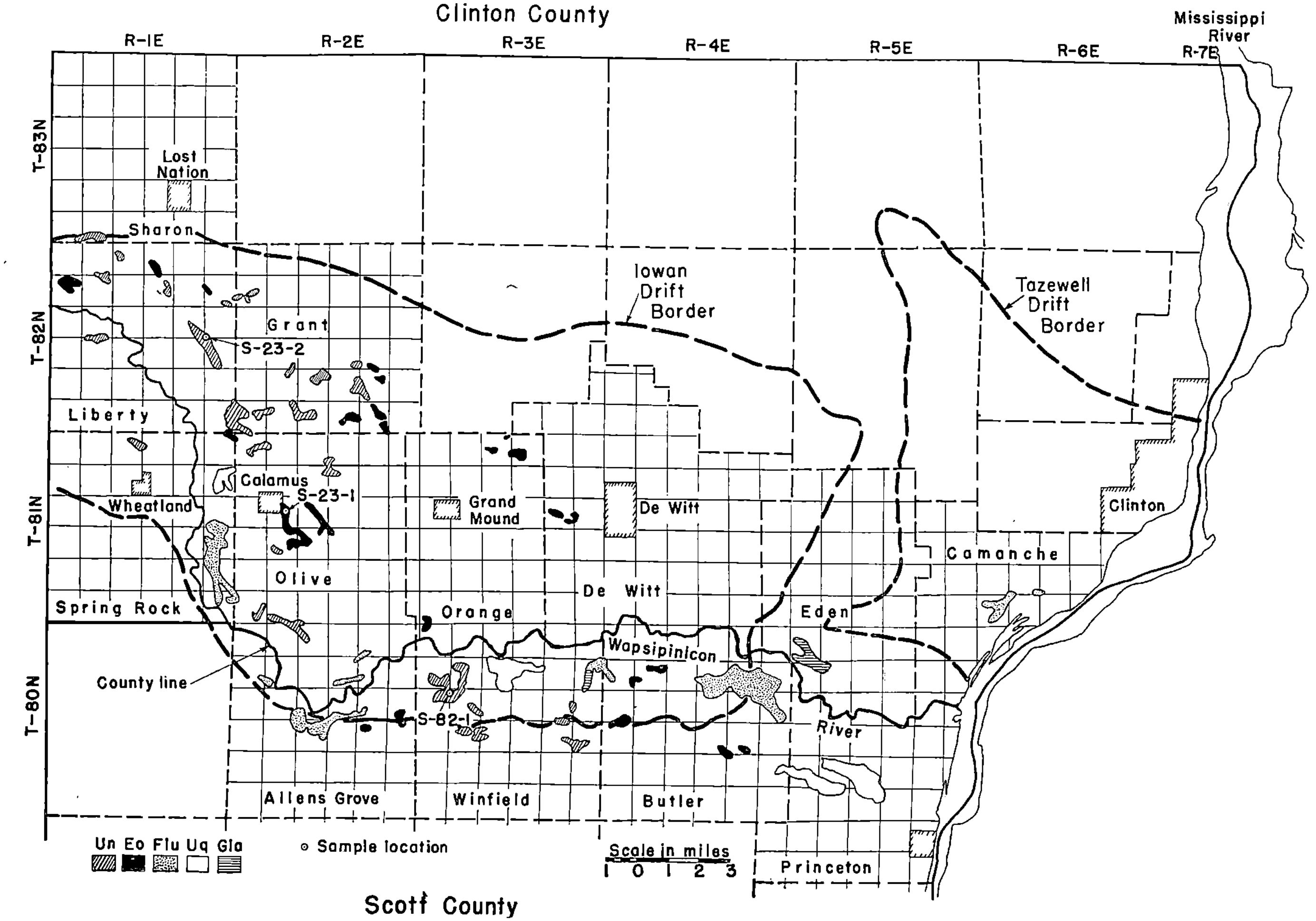

Fig. 44. Sand deposits mapped in Clinton and Scott counties.

PROPERTIES OF FIVE IOWA FINE SANDS

by

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D. T. Davidson, Professor, Civil Engineering
T. Y. Chu, Assistant Professor, Civil Engineering

(Iowa Academy of Science Proceedings, 60:442-464. 1953)

Five sand deposits were sampled by personnel of the Highway Commission under the supervision of a geologist (figure 1). Approximately one ton samples were taken, and a 60 pound portion of each was sent to the Soil Research Laboratory of the Iowa Engineering Experiment Station for determination of fundamental properties. The five sand samples are identified by the numbering system of the Highway Commission (table I).

The term *occurrence and origin* includes information as to the source, areal extent, and uniformity of a deposit wherever determined. *Composition* is broadly interpreted to cover factual information on the components of a sand. *Behavior characteristics*, sometimes called *engineering properties*, are those characteristics, such as shearing strength, plasticity, permeability,

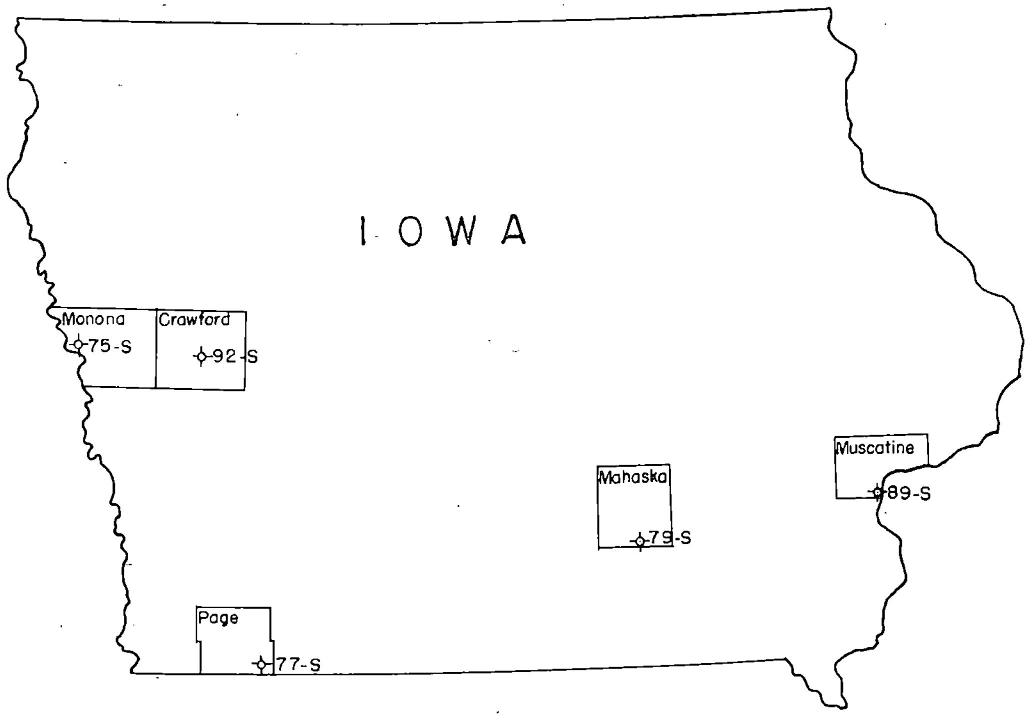

Fig. 1. Distribution of the five fine sand sampling locations.

Table I. Sampling Locations of the Five Iowa Fine Sands.

Sample No.	County	Section	Township North	Range West	Remarks
75-S	Monona	SE¼,NE¼,S-2	83	46	Sampled from the eastern edge of Blue Lake.
77-S	Crawford	SW/C,NW¼,S-14	83	39	Sampled from an abandoned gravel pit at the south edge of Denison.
79-S	Mahaska	NE¼,SE¼,S-25	74	16	Sampled from the north side of the gravel road leading to the Concrete Materials and Construction Company's gravel plant.
89-S	Muscatine	SW¼,NW¼,S-15	76	2	Sampled from a waste pile on the west side of Sewart Road.
92-S	Page	SE¼,NW¼,S-22	69	36	Sampled from a pit locally called the Walker Pit.

Table II. Mechanical Composition of the Five Iowa Fine Sands.

Sample No.	Sample Location	Textural Composition* Sand, %	Silt, %	Clay, %	Sp.G. (25°C)	Ave. Sphericity†	Surface Markings	Texture‡ Coatings	Aggregation Characteristics Amount	Size, mm	Cement
75-S	Monona Co.	96.3	2.9	0.8	2.67	0.65	Dull and smooth	Partially coated by calcareous clay	Rare	1-1½	Calcareous clay
77-S	Crawford Co.	87.6	9.6	2.8	2.66	0.71	Dull and rough (faceted)	Partially coated by calcareous clay	Common	1-3	Calcareous clay
79-S	Mahaska Co.	84.7	11.0	4.3	2.65	0.73	Dull and smooth	Partially coated by ferruginous clay	Abundant	½-1½	Ferruginous clay
89-S	Muscatine Co.	98.1	1.6	0.3	2.67	0.75	Dull and rough (pitted)	Partially coated by iron oxide	Absent	....	....
92-S	Page Co.	92.9	4.3	2.8	2.68	0.61	Dull and rough (pitted)	Completely coated by slightly calcareous clay	Common	1-2	Slighty calcareous clay

* —Sand—2 to 0.074 mm, silt—0.074 to 0.005 mm, clay—less than 0.005 mm.
† —See Rittenhouse chart—figure 5.
‡ —Descriptions apply to most sand particles in the sample.

capillarity, and compactability, which may be used to predict the performance of a sand as a highway construction material.

OCCURRENCE AND ORIGIN

An attempt has been made to determine the occurrence and origin of the fine sand deposits by a review of the pertinent published information and by field studies, augmented wherever possible by maps and aerial photographs.

Monona County deposit

The deposit in Monona County was studied by using maps and aerial photographs before field observations were made. The area where sample 75-S was taken (figure 2) is identified in a report on the geology of Monona County[27]. Blue Lake was the main channel of the Missouri River at the time of the Lewis and Clark expedition in 1804 and the lake must have been cut off between this time and the present. The sand lying to the east of the lake has been reworked by the wind.

Th Missouri River in Monona County meanders in a relatively wide

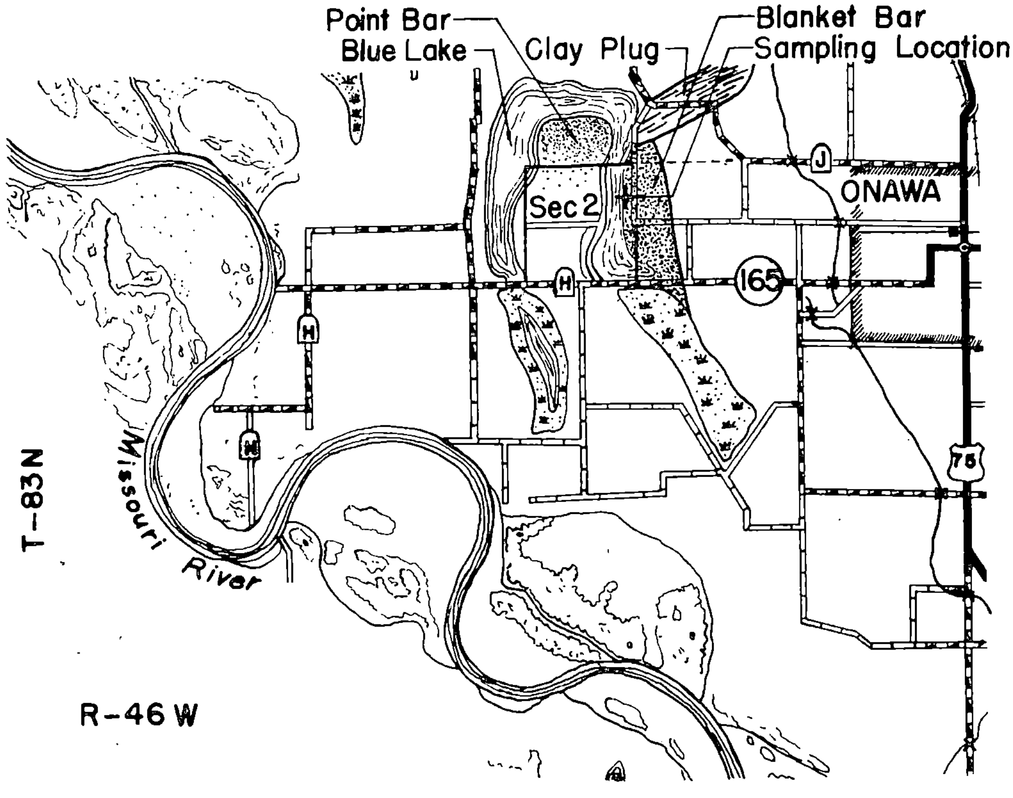

Fig. 2. Sampling location of Sample 75-S and prominent alluvial features related to the blanket bar sampled.

valley which narrows to the south near Council Bluffs and to the north near Sergeant Bluff. In its meandering, a river is constantly changing its course by lateral migration due to removal of material on the concave bank in the meander loops and by abandoning entire meander loops by a process of neck or chute cut-offs. A neck cut-off occurs when the opposite limbs of the stream in a meander have migrated so close together that flood waters spill over the divide separating them and erode it away. This shortens the stream in this area and so increases the gradient that the stream will remain in the cut-off. After the cut-off, the river migrates laterally away from the abandoned loop, which becomes an ox-bow lake. The ox-bow lake rapidly fills with fine grained sediments, usually of silt and clay sizes. This cohesive fine-grained material forms a deposit, or *clay-plug*, in the abandoned channel[12]. The clay-plug is difficult to erode and tends to limit the migration of the meander belt and to cause numerous reverse curves in the stream channel such as the east bend of Blue Lake.

Although the Missouri has neck cut-offs, the chute type of cut-off is more common. In this type of cut-off the river cuts across a point bar through one of the sloughs. The abandoned channel fills with coarser sized material which offers little resistance to erosion, and the stream continues to migrate in the same direction as before. In time it regains the original position before the cut-off. The flood-plain east of Blue Lake as far as Onawa is a complex of these old meander loops which may be readily identified on aerial photographs of the area.

Four types of sand deposits are associated with meandering streams: point bars, blanket bars, natural levee systems, and channel fillings. All four types of deposits are found in the area around Blue Lake.

A point bar is found on the inside bank of curves and is a series of arcuate ridges parallel to the curvature of the meander. The point bar is made up of sand or silty sand in the ridges which are separated by sloughs underlain by silty sand or silty clay (figure 2).

Blanket bars and natural levees are related to each other genetically and are found along the margins of the stream. A blanket bar is deposited along the river where the main current is deflected when the river is in flood. This natural levee is deposited from the sediment laden overflow and is a low, nearly continuous ridge parallel to the stream bank. Blanket bars and natural levees usually are of silty sand or fine sand which is somewhat finer than the material in a point bar. The blanket bar from which sample 75-S was taken occurs on the downstream side of the clay-plug (figure 2).

Channel fillings are generally more variable than either of the other types of deposits and may be of all particle sizes from coarse gravel through clay. They are usually a complex of interbedded gravel and sand intermixed with the finer grained alluvium.

Samples of material from the ridges of the point bar and from the clay-plug were collected as a part of the field investigation. The gradations of samples represent the point bar, the clay-plug, and the blanket bar sampled by the Highway Commission (figure 3). As would be expected the cumulative curves show the material of the point bar to be coarsest and that of the clay-plug finest.

The blanket bar (figure 2) is limited on the north by the clay-plug, to the west by the channel fillings under the present lake, and on the east

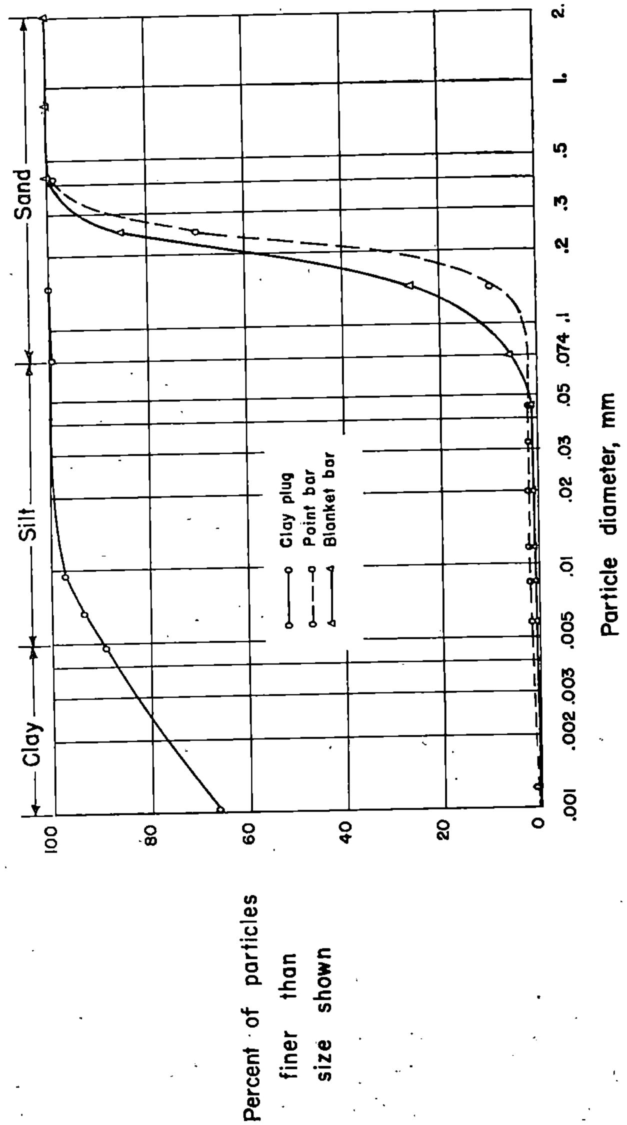

Fig. 3. Particle-size accumulation curves showing gradation of clay plug, point bar, and blanket bar materials from Blue Lake deposits in Monona County.

and south by material which becomes progressively finer textured away from the blanket bar.

The sand represented by sample 75-S was deposited by the river during the Recent epoch and is in part derived from sedimentaries of Cretaceous age, as shown by the presence of Cretaceous microfossils. This material also is probably in part derived from the till plains to the east and north by erosion and selective transportation.

The sands found in the vicinity of Blue Lake should not be considered characteristic of the sands found either upstream or downstream from this area. In any alluvial valley the materials carried and deposited by the stream vary from place to place due to the influence of tributaries as well as to local hydrologic and geologic factors. The effect of a major tributary is often great enough to cause the material deposited along the main stream below it to be quite different from that deposited above.

Crawford County Deposit

Sample 77-S from Crawford County, near Denison, (table I) was taken from an abandoned gravel pit lying to the south of the West Boyer River and at a somewhat higher elevation than the present floodplain. This location has been called the Old Mill Pit[21], and the material from it is identified as fine yellow and gray sand with interbedded gravel approximately 50 feet in thickness. This deposit has not been dated, but other, probably similar, deposits in Crawford County are Loveland in age[17].

The areal extent of the deposit, which may represent a portion of an old river terrace built up by glacial melt waters, was not determined in this investigation. If it proves to be a terrace deposit, it may extend both upstream and downstream parallel to the West Boyer River.

The color of the sand in the gravel pit appears to depend on the state of reduction of the iron, grading from gray at the bottom to a brownish yellow at the top. Three to four feet of gray loess is over the deposit.

Mahaska County Deposit

Sample 79-S from Mahaska County (table I) was taken from a narrow lineal hill bordering the flood plain on the east side of the Des Moines River in a northwest to southeast direction in the vicinity of Eddyville. The deposit is limited to the hill which has a relief of about 50 to 75 feet, a width of 300 to 500 feet, and a length of about two miles.

Other fine sand of the county is identified as aeolian, but this deposit is sometimes identified as a wind-deposited sand derived from the flood plain of the river[4]. Examination of the area on aerial photographs and in the field suggests that the sand may have been deposited by water overflowing a low ridge of glacial till which formed the east side of a conspicuously narrow segment of the valley in this area. This narrow segment of the valley is essentially co-extensive with the length of the sand ridge. The age of the deposit is unknown.

Muscatine County Deposit

Sample 89-S from Muscatine County (table I) was collected from a waste pile discarded in the production of gravel. The waste pile was deposited by a flume carrying the water and fine sediments that passed through the screens of the gravel producing plant. The flume outlet was moved frequently as the waste pile accumulated, and as a result the material is texturally coarser near the flume outlets and grades radially into finer sizes.

Page County Deposit

The geological origin of the deposit from which sample 92-S from Page County was taken is different from that of the other deposits. This deposit is a type of alluvial fan and is located in the valley of the Nodaway River (table I). The material seems to have been derived from erosion of the Kansan till uplands by small tributaries of the Nodaway River, which deposited the sand and gravel as their gradients were decreased when they reached the floodplain of the Nodaway.

COMPOSITION

The preceding discussion of occurrence and origin applies to the sand deposits as a whole. Additional field work is needed to determine whether the properties of five sand samples taken from these deposits by Highway Commission personnel are representative of the deposits from which they were taken.

Mechanical Composition

Mechanical composition covers such information as the size, specific gravity, shape (sphericity), surface texture, and aggregation characteristics of the sand particles.

Size. Particle-size determinations were made by the modified A.S.T.M. standard method D422-51[10], (figure 4 and table II). Although all samples were classified texturally by the U. S. Bureau of Public Roads system[22] as sand, their gradation differed considerably; and some of the samples contained appreciable amounts of silt and clay-size material.

Specific gravity. The specific gravity of each sand sample was determined by A.S.T.M. method D854-45T[3] (table II). The specific gravity of each sample was close to that of quartz, which is 2.66.

Shape. The shape or sphericity of sand particles is directly related to their occurrence and origin and should have an important effect on their behavior characteristics. While various methods have been devised for estimating the average sphericity of a sample [23, 28, 29, 30], there is a need for a more exact method.

The Rittenhouse chart [18, 26] was used for estimating particle sphericity (figure 5). The sand particles were viewed through either a petrographic or a binocular microscope, depending on the particle sizes being studied; and their sphericities were estimated by comparing sand particle outlines with the outlines in the chart of particles of known sphericity.

$$\text{Sphericity} = \frac{\text{Intermediate particle diameter}}{\text{Maximum particle diameter}}$$

In using the chart for estimating sphericity, it is assumed that the minimum particle diameter is normal to the line of sight and that the outline of the particle as viewed on the slide shows the maximum and intermediate diameters.

The selection of particles from the whole sand sample that would repre-

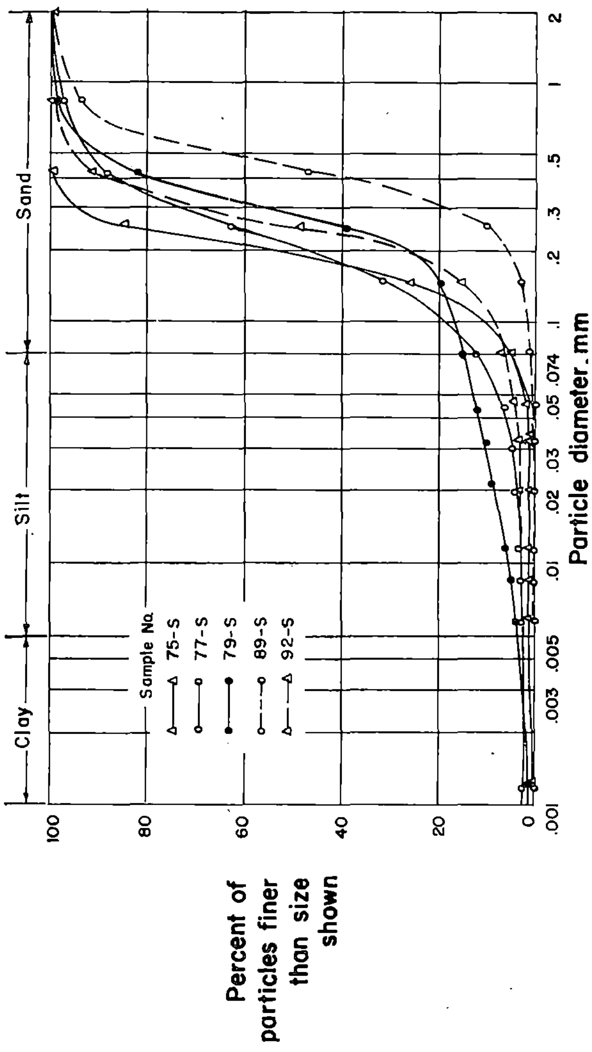

Fig. 4. Particle-size accumulation curves for the five Iowa fine sands.

sent the average sphericity of the sample was difficult, since the tendency was to choose only the larger particles. To avoid doing this, particle-size ranges which bracket the median particle diameters and are thought to be representative of the sand and silt portion of the samples were used for the shape determinations. The median diameter is the particle diameter associated with the 50 percent line of the cumulative curve.

Sample No.	Particle-Size Range
75-S	0.250 to 0.074 mm.
77-S	0.250 to 0.074 mm.
79-S	0.420 to 0.250 mm.
89-S	0.420 to 0.250 mm.
92-S	0.250 to 0.074 mm.

Clay and iron coatings were removed from samples used in the shape study[15].

Sample 89-S from Muscatine County had the highest average sphericity,

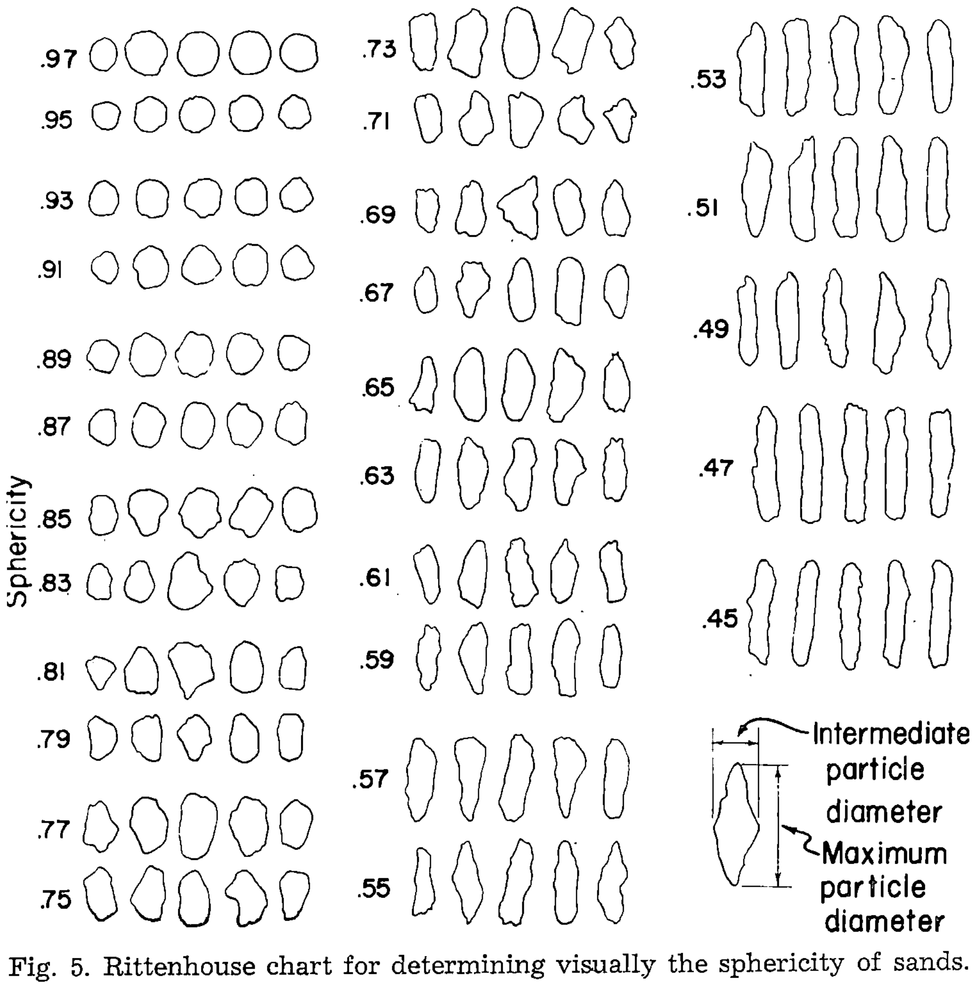

Fig. 5. Rittenhouse chart for determining visually the sphericity of sands.

and sample 92-S from Page County had the lowest (table II). In general the larger particles in all samples showed the greatest degree of sphericity.

Surface texture covers both the markings and the coatings on the surface of particles. Markings on particles result from the effects of transportation and of diagenesis. Like particle shape, surface markings vary with the size of the particles. Unlike particle shape, however, the kind of markings rather than the amount varies with the size. At the present time there is no well defined procedure for evaluating surface markings. In a suggested two word system of describing markings, the first word refers to luster, and the second to the surface relief of the sand particle[19]. This system was used herein. Coatings on particles may be especially significant in stabilization studies, since they may have an important effect on the interaction between the mineral particles and chemical additives. Clay, lime, and iron oxide coatings are most commonly found on the surface of sand-size particles. These coatings may completely coat the particle, or they may be only in the surface depressions. Important factors in connection with coatings are: type and amount, reactivity, ease of removal, and effect on aggregation. Coatings are seldom determined quantitatively, rather their appearance is described (table II).

Markings and coatings on the sand-size material of the five Iowa fine sands were determined with a binocular microscope. Samples representative of the whole, uncleaned sands were used for studying coatings; similar cleaned samples were used for determining markings[15].

Aggregation is the cementation of two or more sand-size particles to form a larger unit. It is closely related to coatings on the particles in that coatings of clay, lime, iron oxide, or organic matter (humus) alone or intermixed provide the cementation necessary for aggregation.

Aggregation in the five Iowa sands was determined with a binocular microscope. The samples used for this purpose were representative of the whole, uncleaned sands. The water-stability of aggregates in the samples was estimated by placing a drop of water on the aggregate and noting any resulting disintegration.

The relative amount of aggregation, the aggregate sizes, and the principal cementing agent responsible for aggregation in each sample were all determined (table II). Aggregation of the smaller sand particles was found in all samples except sample 89-S. The aggregates in samples 75-S and 77-S were most water-stable, probably because of the flocculated state of the clay coatings. The clay coatings in samples 79-S and 92-S appeared to be dispersed.

Mineralogical Composition

The mineralogy of the five fine sands was determined by both petrographic and differential thermal analyses. The primary minerals and calcite in each sand were identified by petrographic methods. The predominant kind of clay mineral in each sand was estimated by the differential thermal analysis method.

Petrographic Analysis. Representative portions of each sand were separated into particle-size ranges for the petrographic studies (figure 6). Following the size separations, each size range was further separated into light and heavy mineral fractions by a heavy liquid (bromoform) fractionation pro-

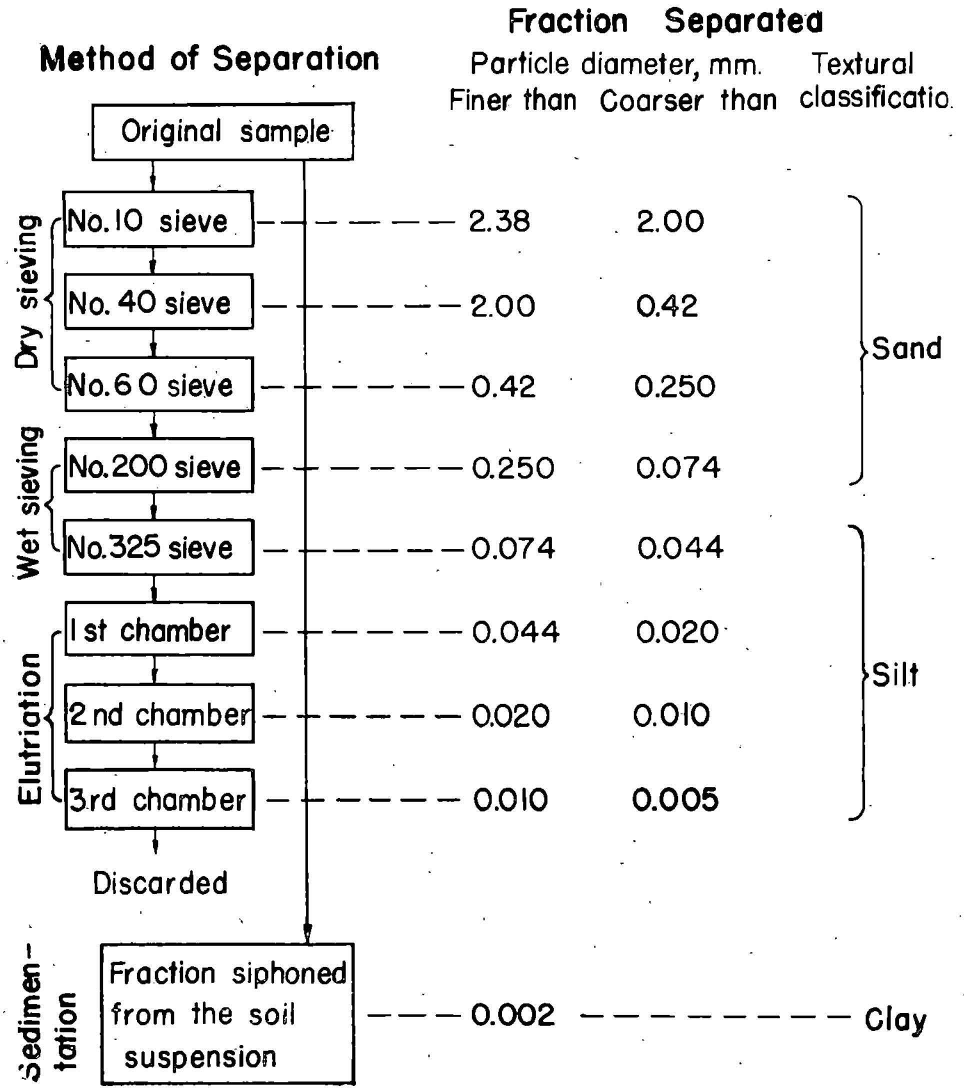

Fig. 6. Separation of sand samples into different fractions for determination of their mineralogical composition.

cedure[19]. Commercially prepared thin sections mounted in bakelite proved unsatisfactory because of the high refractive index of bakelite. Particles representative of each of the light and heavy fractions were mounted on glass slides for microscopic examination.

The results of the petrographic analyses show that light minerals predominate in all sands, with quartz being the most abundant (table III). The percentage of heavy minerals present in each of the sands was relatively small and they were not evenly distributed among the different size ranges (figure 7). *Rock fragments* are the particles composed of more than one mineral. The average composition of the rock fragments would probably be similar to that of granite. Calcite or calcium carbonate is a secondary mineral, but since it can be identified microscopically, it is included in the petrographic analysis.

The large percentage of light minerals, especially quartz, in all the fine sand samples, is in agreement with the reaction (stability) series, which shows the light minerals to be relatively more stable in nature than the heavy minerals and quartz to be the most stable of all primary minerals[6, 9]. The primary minerals in the order of increasing stability are:

Ferro-Magnesian (heavy minerals) $\leqslant$ plagioclase feldspar $<$ potash feldspar$<$quartz

Calcite, a secondary mineral, is not included in the series. In a humid environment calcite is unstable due to its solubility. The stability of the primary minerals may decrease in the presence of certain chemical additives used in soil stabilization work; but, in general, their order of stability should remain the same.

TABLE III. LIGHT AND HEAVY MINERAL COMPOSITION OF THE FIVE IOWA FINE SANDS.

Kind of Mineral	75-S Monona Co.	77-S Crawford Co.	Sample 79-S Mahaska Co.	89-S Muscatine Co.	92-S Page Co.
LIGHT MINERALS, %	93.8	98.2	98.8	96.5	98.6
Quartz, %	62.0	75.0	76.4	68.7	72.6
Potash Feldspar, %	8.6	9.6	10.6	7.9	4.6
Plagioclase Feldspar, %	5.3	1.6	1.6	2.1	2.6
Rock Fragments, %	13.4	5.7	9.2	13.8	15.6
Calcite, %	3.0	5.0	0.5	3.0	0.5
Other, %	1.5	1.3	0.5	1.0	2.7
HEAVY MINERALS, %	6.2	1.8	1.2	3.5	1.4
Opaque Minerals, %	4.0	0.1	0.7	2.4	0.7
Amphibole, %	1.0	1.0	0.3	0.8	0.2
Pyroxene, %	1.0	0.5	0.1	0.2	0.2
Zircon, %	0.1	0.1	Trace	Trace	0.1
Tourmaline, %	Trace	0.1	Trace	Absent	Absent
Garnet, %	Trace	Absent	Absent	Absent	0,1
Mica	Trace	Absent	Absent	Absent	Trace

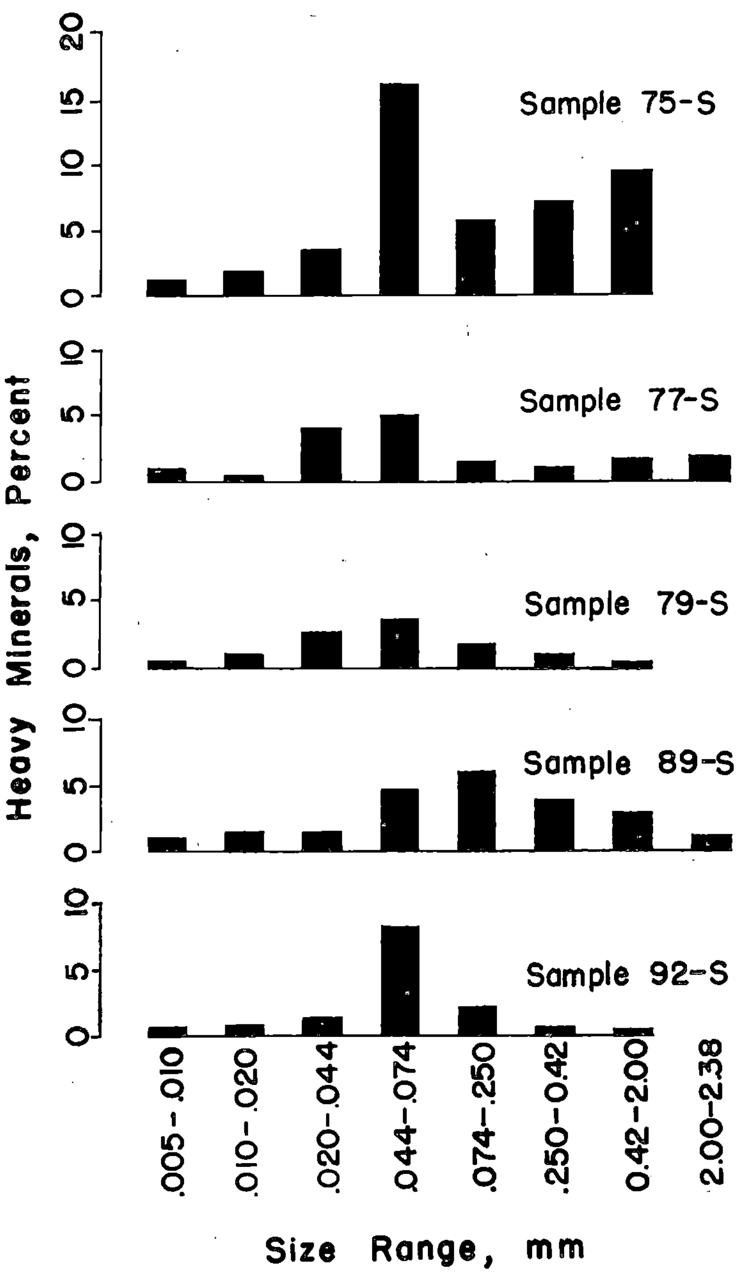

Fig. 7. Variation of amount of heavy minerals in different size ranges of the five Iowa fine sands.

Differential Thermal Analysis. The minus 0.002 mm. fractions of the five sands obtained by sedimentation (figure 6) were used for the differential thermal analyses because most of the clay minerals occur in this particle-size range. While small amounts of non-clay materials may be in this size range, in inorganic soils they would not mask clay mineral thermal reactions. Differential thermal analysis experiments with the minus 0.074 mm. fractions of the sands showed that quartz and carbonates usually did mask clay mineral reactions (table IV).

The differential thermal analysis apparatus and procedure were used[20] and the interpretations of thermal curves were based on relatively pure clay mineral reference curves[2, 13]. The clay mineral content of soils has engineering significance[16, 25]. Illite was present in all sands, and sample 75-S contained montmorillonite in addition to illite (table IV).

Chemical Composition

Only a limited amount of information is available on the influence of chemical composition and related characteristics on those properties of soil of interest to the highway enigneer. The engineering significance of soil water pH and of the presence in soils of constituents such as carbonates, organic matter, and sulfates have been discussed[8], and the relationships between whole soil cation exchange capacity and engineering properties have been presented[11]. The presence of free iron oxide in soils has not received much attention from engineers, but where present it should be an important factor in some kinds of soil stabilization work.

In the fine sand investigation, quantitative tests were employed to estimate the proportions of the above mentioned constituents in each of the sands, as well as to determine their acidity or alkalinity (pH value) and their cation exchange capacity:

TABLE IV. INTERPRETATIONS FROM THERMAL CURVES OF TWO PARTICLE-SIZE RANGES OF EACH OF THE FIVE IOWA FINE SANDS.

Sample No. and Location	Sample Size Range Analyzed, mm	Predominant Kinds of Clay Minerals	Carbonates	Quartz
75-S	−0.074	Illite	Present	Present
Monona Co.	−0.002	Illite and Montmorillonite	Absent	Absent
77-S	−0.074	Illite (?)	Present	Present
Crawford Co.	−0.002	Illite	Absent	Absent
79-S	−0.074	Masked	Present(?)	Present
Mahaska Co.	−0.002	Illite	Trace(?)	Absent
89-S	−0.074	Masked	Present	Present
Muscatine Co.	−0.002	Illite	Trace(?)	Absent
92-S	−0.074	Masked	Absent	Present
Page Co.	−0.002	Illite	Absent	Absent

1. Organic matter—Dichromate oxidation method[8].
2. Carbonates ($CaCO_3$)—Acid decomposition method[24].
3. Sulfate (SO_3)—Water soluble sulfate determination[8].
4. Free iron oxide[15].
5. pH value—Electrometric determination, 15g soil in 30 ml water.
6. Cation exchange capacity (whole sand)—Ammonium acetate method[11].

The organic matter content of all sands was low, and no sulfate salts were found to be present (table V). Carbonates were present in all sands, and those containing the greater amounts had a corresponding higher pH value; the pH values varied from slightly alkaline to alkaline. Free iron oxide occurred as particle coatings or as individual grains. In inorganic soils such as the five fine sands, cation exchange capacity is mainly dependent on the amount and kind of clay minerals present. Sample 75-S had the highest cation exchange capacity despite the fact that it had next to the lowest clay content (table II). This is probably due to the presence of montmorillonite in this sample.

BEHAVIOR CHARACTERISTICS

The quality of fine sands as construction materials can in general be rated on the basis of their composition. However, the rating of sands is sometimes difficult because the relationship between composition and performance is not fully established. Laboratory tests to determine behavior characteristics of sands are therefore necessary to evaluate sands more fully as engineering materials.

The behavior characteristics needed for rating the suitability of sands depends upon the use which will be made of them. For example, the behavior characteristics which are significant for sands to be stabilized with Portland cement may not be significant for sands to be stabilized with bituminous materials. Since the specific use which will be made of the five fine sands has not been determined, experiments were performed to determine their general behavior characteristics only.

Tests Used

The behavior characteristics of the five sand samples which were determined by four different tests (table VI).

TABLE V. SOME CHEMICAL CONSTITUENTS AND RELATED CHARACTERISTICS OF THE FIVE IOWA FINE SANDS.

No.	Sample Location	Organic Matter, %	Carbonates, % $CaCO_3$	Sulfate, % SO_3	Free Iron Oxide, %	pH	Cat. Ex. Cap., m.e./100 g
75-S	Monona Co.	0.16	3.8	Absent	0.26	8.2	2.3
77-S	Crawford Co.	0.07	3.0	Absent	0.15	8.6	2.0
79-S	Mahaska Co.	0.17	1.4	Absent	0.17	7.4	1.5
89-S	Muscatine Co.	0.09	3.5	Absent	0.24	8.0	1.0
92-S	Page Co.	0.12	1.5	Absent	0.13	7.1	2.1

TABLE VI. SOME BEHAVIOR CHARACTERISTICS OF THE FIVE IOWA FINE SANDS.

Sample		Standard Proctor Density Test			Permeability Test (sample in loose state)			Direct Shear Test	
No.	Location	Max. Dry Density,* g/cc	Opt. Moist. Content,* Percent	Porosity at Max. Density Percent	Porosity, Percent	Coefficient of Permeability ft./day	Capillary Rise, in.	Cohesion, psi.	Angle of Internal Friction
75-S	Monona Co.	1.61	16.3	39.6	42.4	48.4	13	1.7	36° 4′
77-S	Crawford Co.	1.74	12.4	34.5	43.4	24.3	14	1.6	35° 38′
79-S	Mahaska Co.	1.89	10.0	28.6	39.4	7.3	13	1.6	37° 6′
89-S	Muscatine Co.	1.72	15.0	35.5	37.4	208.5	9	2.4	34° 15′
92-S	Page Co.	1.72	14.4	35.7	45.9	70.7	11	2.9	35° 29′

* Data furnished by the Iowa State Highway Commission.

Standard Proctor Density Test. The standard A.S.T.M test D698-42T[3] was used to determine the maximum dry density and the optimum moisture content. The porosity of the sands at maximum dry density was also computed.

Permeability Test. The test procedure for determining permeability was similar to that of the Barber method[5] with the following exceptions:

1. All samples were tested in a loose state for permeability. Their density was approximately the same as the unit weight determined by the standard A.S.T.M. test C29-42. The porosity of each sample was computed.
2. All samples were immersed in water for 24 hours before being tested for permeability.

Capillarity Test. The test procedure for determining capillarity was similar to Herman's method[7] except that test samples were immersed for 24 hours before being tested for capillary rise.

Direct Shear Test. The procedure for the direct shear test was patterned after the Bureau of Public Roads method[7] with the following modifications:

1. The sands were tested for direct shearing strength at maximum standard Proctor density and at optimum moisture content.
2. The diameter of test specimens was 2½ inches and the height ½ inch.
3. The rate of shear displacement was 0.02 inches per minute.
4. Normal loads of 1, 2, and 3 tons per square foot were used in the determination of the maximum shearing stresses. The cohesion and the angle of internal friction were determined on the basis of these stresses.

Test Results

All the five Iowa fine sands were non-plastic according to the Atterburg limits data obtained by the Iowa State Highway Commission, and all were classified by the B.P.R. system[1] as Group A-3 soils (table VI).

Sample 79-S had the highest maximum dry density. This sample had a better gradation than the other samples (figure 4), and this is believed to be the principal reason for its higher density.

The difference between the porosity of the five sands at maximum density and in the loose state is a measure of the compactibility of each sand. The greater the difference the more effectively the sand can be compacted. Data show that the maximum density porosity of samples 89-S and 75-S was only about 2 and 3 percent lower respectively than the loose state porosity.

The maximum density porosity of the other samples was near or over 9 percent lower than the loose state porosity. In other words, the compactibility of samples 75-S and 89-S was significantly lower than the others This is probably due mainly to their relatively low clay contents (table II), since moist clay will help to lubricate the sand particles and facilitate their reorientation during compaction.

Sample 89-S had the highest coefficient of permeability, but its porosity in the loose state was the lowest. This can possibly be explained by its coarse texture and absence of aggregation (table II).

As compared with the differences in permeability values the variation in capillary rise was relatively small in the five samples. Sample 89-S, which had the highest permeability, had the lowest capillary rise, as would be expected.

The cohesion and angle of internal friction determined by the direct shear tests showed only slight differences in the five samples. No apparent correlation of shearing strength with other properties of the sands was found.

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