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Property Variations in the Peorian Loess of Southwestern Iowa

By D. T. Davidson and R. L. Handy

It is widely recognized in Iowa that there are not enough economically available supplies of sand, gravel, and rock in the state to meet the road building needs of the present and future. While certain counties have been favored more than others with aggregate deposits, this statement applies to the entire state, if a long-range view point 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. For this purpose, a project entitled An Investigation of Loess and Glacial Till Materials in Iowa was recently (September, 1950) established at the Engineering Experiment Station of Iowa State College. The project is being carried on under contract with the Iowa State Highway Commission and under the sponsorship of the Iowa Highway Research Board. It is supported by funds supplied by the Commission and the U. S. Bureau of Public Roads. 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.

Southwestern Iowa Loess Investigation

The soil material selected for the first project investigation is the Peorian loess[1] in the southwestern Iowa area shown in Fig. 1. The Peorian loess in the area forms a massive surface deposit which

[1]Also called Wisconsin loess in the literature.

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mantles older (pre-Wisconsin) loesses and glacial deposits. This loess is believed to have accumulated during and immediately following glaciations of the Wisconsin glacial stage 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 by Dr. R. V. Ruhe.[2] 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 Fig. 1 has been described in the literature (1, 2)[3] as loess depositional and loess mantled erosional. The principal soil association areas are the Monona-Ida-Hamburg and the Marshall (3).

In connection with the study of areal and stratigraphic variation of physical and chemical properties of the loess, over one hundred samples have been taken along five traverses (Fig. 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 presented in this paper 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) (4).
3. Field moisture content (4).
4. Mechanical analysis (A.S.T.M. Method: D422-51 as modified by Davidson and Chu) (5).
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).

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[2]Personal communication from Dr. Ruhe who formerly was Assistant Professor of Geology at Iowa State College.

[3]The numbers in parentheses refer to the list of references appended to this paper.

9. Textural classification (Bureau of Public Road System) (6).
10. Engineering classification (revised Bureau of Public Roads System) (7).
11. Carbonate content, expressed as percent $CaCO_3$ (rapid titration method) (8).
12. pH (hydrogen ion meter).
13. Organic matter content (dichromate oxidation method) (9).
14. Cation exchange capacity (ammonium acetate method) (10).
15. Differential thermal analysis (method described by Hauth and Davidson) (11).

Complete details on the tests may be obtained from the publications cited.

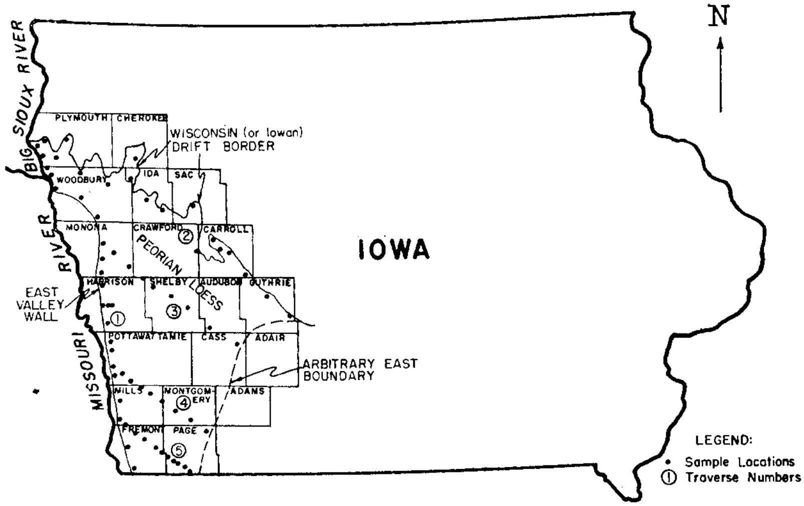

FIG. 1 - LOCATIONS OF SAMPLING TRAVERSES IN PEORIAN LOESS OF SOUTHWESTERN IOWA

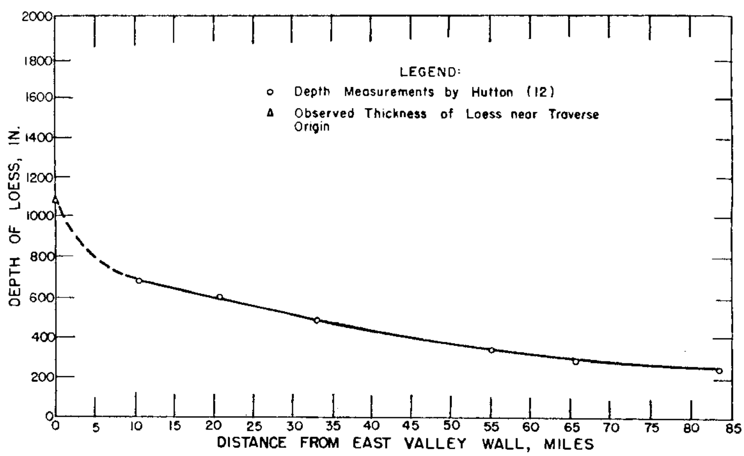

FIG. 2 - VARIATION IN MAXIMUM THICKNESS OF PEORIAN LOESS ALONG TRAVERSE 3.

Table 1

Sample Locations Along Traverse 3

Sample No.	Dist. from East Valley Wall, miles	Sampling[a] Depth, ft.	Location				Soil Series
			County	Section	Township North	Range West	
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.

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Property Variations Along Traverse 3

Traverse Description

In the present paper, only the property variations along traverse 3 shown in Fig. 1 will be discussed. In a study of surface soils derived from Peorian loess in southwestern Iowa, Hutton (12) made depth measurements of the loess along essentially this same traverse (Hutton's traverse 1)[4]. 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 80 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 1 presents the locations of samples obtained along the traverse. The soil series at the location from which each sample was taken is also shown.

Depth Measurements

Depth measurements of the Peorian loess along traverse 3, presented in Fig. 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[5], were made by Hutton (12); they represent the vertical distance from the earth's surface to the bottom of the Peorian loess deposit. 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 as found by Smith (14) and Krumbein (15) for similar traverses in the Peorian loess in Illinois. 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. Hutton (12) has reported morphological studies of loess-derived surface soils along the traverse.

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[4]Hutton's traverse 1 extended southeast to the Iowa-Missouri state line in southeastern Wayne County.

[5]The thickness of the Peorian loess at the east valley wall is the maximum thickness observed in the vicinity of the traverse origin.

Table 2

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.

In-Place Properties

As summarized in Table 2, 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 unoxidized 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 of the traverse, and is, in fact, unobserved at the west end. Hobbs (16) has suggested that the depth of oxidation is a measure of the permeability to aqueous solutions. The centrifuge moisture equivalent data of the present study (Table 3) 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. Similar trends in oxidation were noted by Shimek (17).

Root tubules, or decayed roots, were noted at several sample locations. They are especially noticeable in the unoxidized loess and 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 lime 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 2) along the traverse. As seen in Fig. 3, there is a linear increase of in-place density with distance from the east valley wall. 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 2 and Fig. 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 by the hydrometer method as modified by Davidson and Chu (5). Sodium metaphosphate was used as the dispersing agent. The sand fraction was separated by mechanical sieving.

As seen in Table 3, the texture of the loess ranges from silty loam

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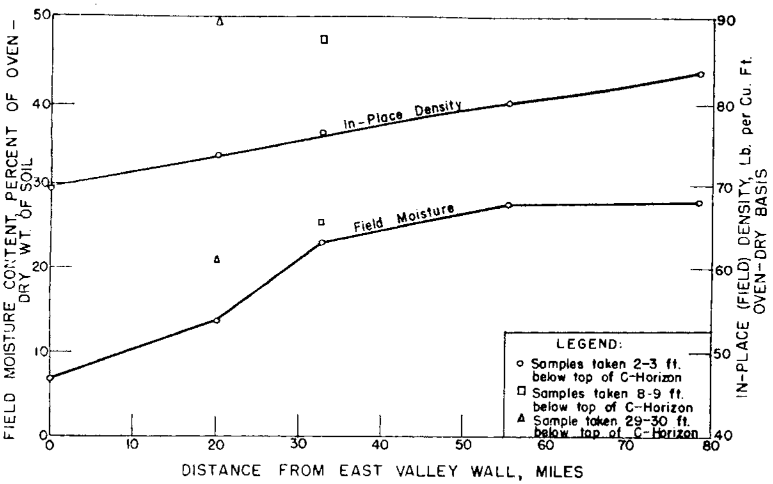

FIG. 3 – VARIATION IN FIELD MOISTURE CONTENT AND IN-PLACE DENSITY OF PEORIAN LOESS ALONG TRAVERSE 3.

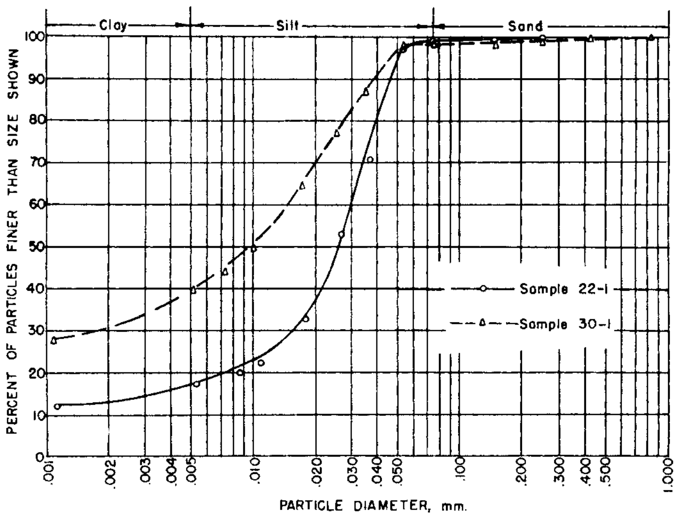

FIG. 4 – PARTICLE-SIZE ACCUMULATION CURVES FOR SAMPLES OBTAINED AT WEST (22-1) AND EAST (30-1) ENDS OF TRAVERSE 3.

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

The relationship between textural composition of the loess and distance from the valley wall is shown in the lower part of Fig. 5. The sand content, including small lime concretions, is low and

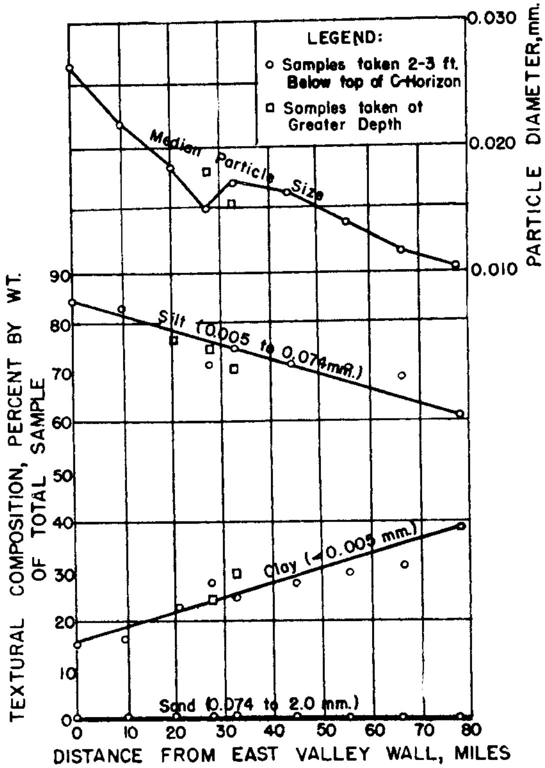

FIG. 5 – VARIATION IN PARTICLE SIZE OF PEORIAN LOESS ALONG TRAVERSE 3.

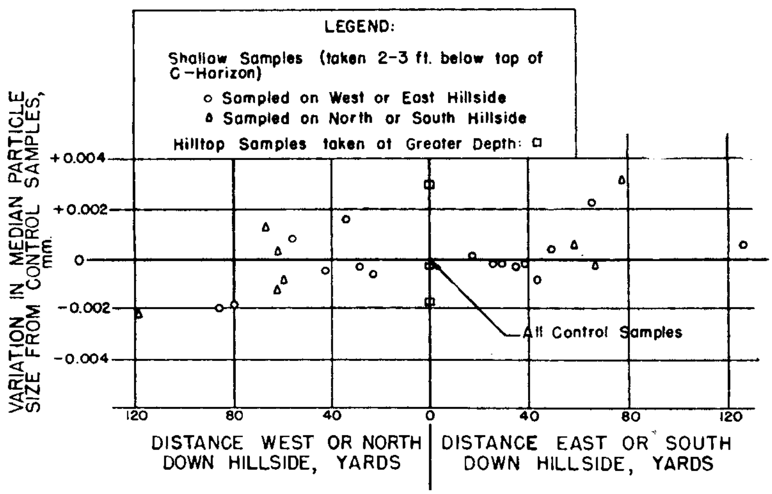

FIG. 6 – VARIATIONS IN MEDIAN PARTICLE SIZE OF HILLSIDE SAMPLES FROM THE CONTROL (SHALLOW HILLTOP) SAMPLES.

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 in the upper part of Fig. 5. Similar trends in the Peorian loess have been reported by Kay and Graham (1) and Hutton (12) in Iowa, Smith (14) in Illinois, and Swineford and Frye (18) in Kansas. On the basis of the data presented, there appears to be no large or consistent variation in textural composition with depth. Further studies of particle-size variations with depth in the loess are now under way.

Hillside Texture Variation. As previously explained, the control samples were taken on ridges or hilltops at the depth of 2 to 3 ft. below the top of the C-horizon. In order 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 ft. 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.

In Fig. 6, the variation in median particle diameter between each hillside sample and its hilltop control sample is plotted against distance from the hilltop. As can be seen from the graph, there is no consistent trend towards a coarser or finer particle size in any direction downhill. Also, the hillside variations appear to be of the same order of magnitude as the stratigraphic variations. Particle-size accumulation curves for the hillside samples are practically identical to those of the control samples.

Engineering Properties

Table 3 presents data showing the variation in some physical properties commonly used to predict the behavior characteristics of engineering soils. The significance of these engineering properties is discussed by Allen and others (19, 20, 21). The trends of the plasticity index, shrinkage limit[6], 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.

[6]A decrease in the shrinkage limit denotes an increase in shrinkage characteristics.

Table 3

Engineering Properties of Peorian Loess Along Traverse 3

Sample No.	Dist. from East Valley Wall, miles	Sampling Depth[a], ft.	Physical Test Values				B.P.R.[c] Classification	
			Plasticity Index, %[b]	Shrinkage Limit, %[b]	Centrifuge Moisture Equivalent %[b]	Specific Gravity, 25°C/40°C	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.

The sharp increase in the plasticity index of the loess (Fig. 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, described by Kay and Graham (1) as loess depositional topography. The change in the B.P.R. engineering classification of the loess (Table 3) 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. 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 characteritics of A-6 soils, but are more subject to shrinkage and swelling.

Chemical Properties

The variations in some chemical properties of the Peorian loess along the traverse are shown in Table 4. The carbonate content, expressed as present $CaCO_3$, is highest at the valley wall, immediately adjacent to the river flood plain. Carbonate 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 more prominent 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 cation exchange capacity data presented in Table 4 and Fig. 8 represent the whole soil material. The increase in cation exchange capacity with distance away from the valley wall chiefly reflects the increase in the amount of clay in the loess. 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 constitu-

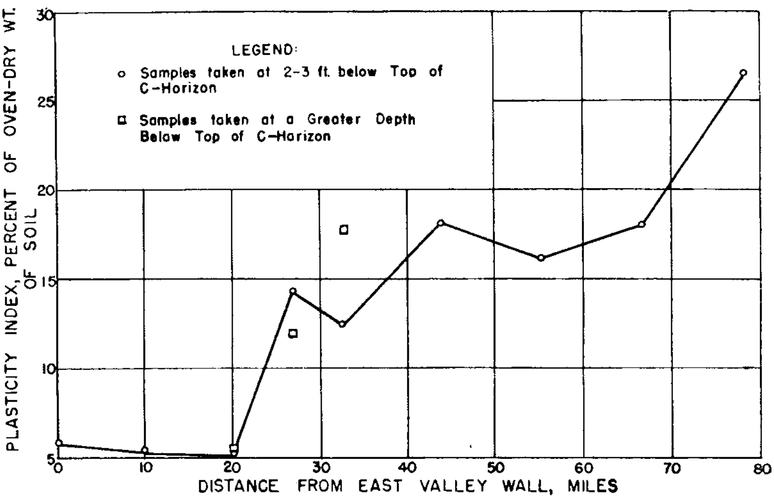

FIG. 7 - VARIATION IN PLASTICITY INDEX OF PEORIAN LOESS ALONG TRAVERSE 3.

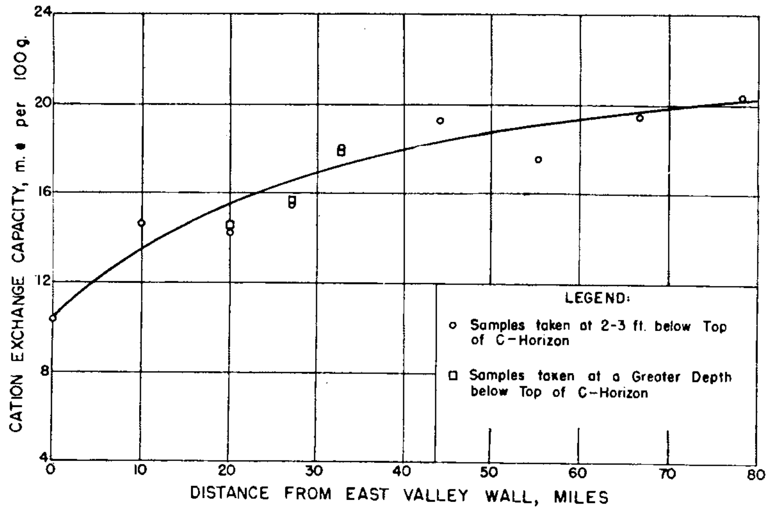

FIG. 8 - VARIATION IN CATION EXCHANGE CAPACITY OF PEORIAN LOESS ALONG TRAVERSE 3

ents, particularly the clay minerals. The apparatus and test method used to obtain the thermal curves discussed in this paper have been described by Hauth and Davidson (11). The curves shown in Fig. 9 for alternate samples along the traverse represent the entire loess fraction without any pre-treatment. The presence of quartz in all samples is denoted by the nipple-like peak at about 573 degrees C. protruding from the endothermic reaction. The prominent endoth-

Table 4

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.

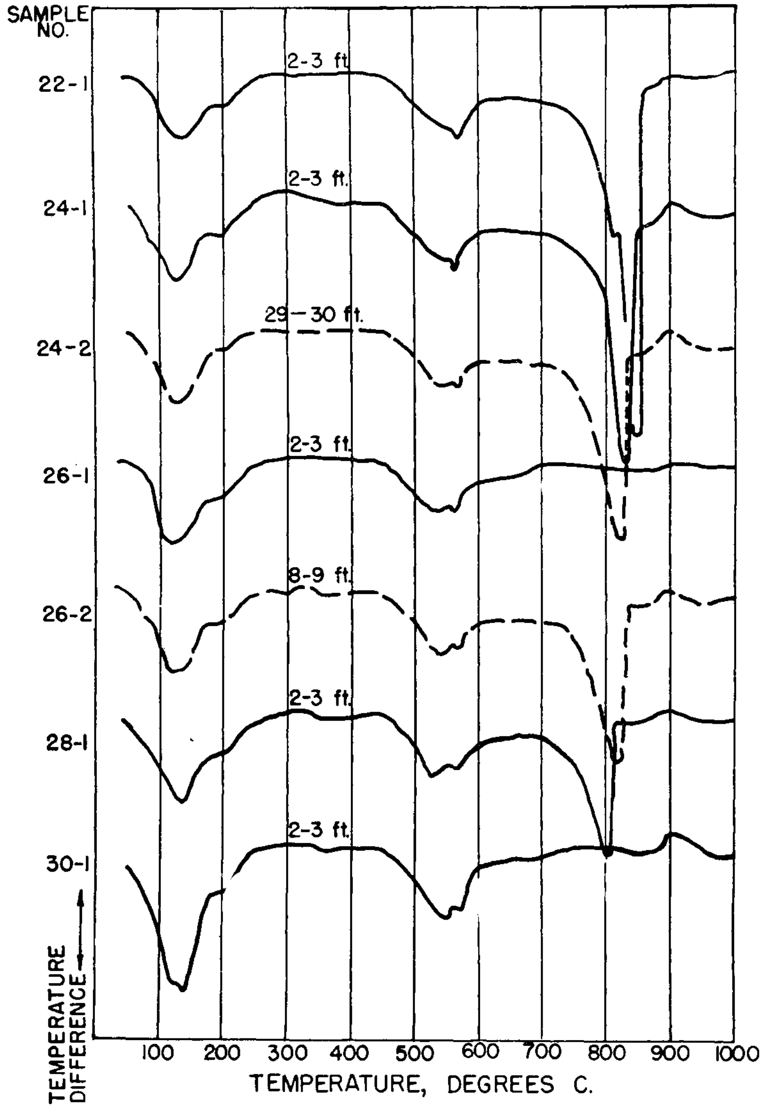

FIG. 9 – THERMAL CURVES OF ALTERNATE SAMPLES ALONG TRAVERSE 3. SAMPLING DEPTH BELOW TOP OF C-HORIZON IS SHOWN ON CURVES.

ermic reaction between 800 and 900 degrees C. shows the high carbonate content of the unleached samples (samples 22-1, 24-1, 24-2, 26-2, 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 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 degrees C. in the case of illites, and between 600 and 700 degrees C. for the montmorillonites. An inspection of the thermal curves in Fig. 9 shows that for all samples the second endothermic reaction occurs in the temperature range 500-600 degrees C., thereby indicating that illite-type minerals are predominant in the clay fraction. A more detailed study is now in progress to determine more definitely the mineralogy of the Peorian loess of southwestern Iowa. The U. S. Bureau of Reclamation has reported (22) a predominance of montmorillonite-type clay minerals in loess (presumably Peorian) samples from Trenton Dam, Missouri River Basin Project in Nebraska.

Conclusions

The following conclusions apply to the Peorian loess along traverse 3 in southwestern Iowa; see Fig. 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 remaider of the traverse.

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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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