STUDIES OF THE CLAY FRACTION OF SOUTHWESTERN IOWA LOESS

By

D. T. DAVIDSON and R. L. HANDY

Iowa Engineering Experiment Station, Iowa State College, Ames, Iowa

ABSTRACT

This paper presents data on clay-size material in the loess of southwestern Iowa. Most of the loess samples studied are Wisconsin in age. Regional distribution of clay-size material in the loess is discussed, and data are given on the modes of occurrence of clay in the loess. The following test methods were used to study the clay fractions of selected loess samples: Mechanical analysis, differential thermal analysis, cation-exchange determinations, refractive index determinations, and x-ray diffraction techniques. These tests indicate a uniformity in clay-mineral composition, with montmorillonite and illite group minerals predominating. Clay contents from mechanical analysis are correlated with various properties of the loess; in most cases the properties appear to be linear functions of the clay content. The plastic limit is discussed in detail.

INTRODUCTION

Many sections of Iowa, and of the United States, are now suffering shortages of gravel and rock for road building. Also, since present sources of these materials are rapidly being depleted, more widespread and severe shortages of aggregate are predicted for the future. A solution to this problem is to treat or process readily available materials to increase their all-weather stability for road construction. Possibilities for such treatments of various soil materials are now being investigated by the Iowa Engineering Experiment Station. Because of the widespread distribution of Wisconsin (Peorian) loess in Iowa, this material was selected first for study and evaluation for stabilization purposes. The investigation is being conducted in two phases: (1) a study of properties and variations in properties of the material, and (2) an evaluation of various stabilizing agents used with the material. This paper reports information obtained in the first-phase studies of the loess in southwestern Iowa. Similar studies of Wisconsin loess are now under way in eastern and northeastern Iowa, but at present the data for these areas are insufficient for inclusion in this paper.

Importance of Clay

It is now recognized that the clay minerals in soils and sediments have a profound influence on engineering properties: The study of the clay fraction is an essential part of any attempt to stabilize a soil material for roads. Specifically, it is desirable to measure the influence of the amount and composition of the clay fraction on soil properties.

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Distribution of Clay in the Loess

Clay contents in the Wisconsin loess of southwestern Iowa vary rather systematically over the entire area (Fig. 1). In general, there is a higher proportion of clay to the south and away from the Missouri River Valley. Since loess is considered by most geologists to be deposited by the wind, the common explanation for this is that more silt-size material settled out of the air near the major sources of the loess, and the finer clay-size materials were carried farther inland. Studies of the loess (Davidson and Handy, 1952, p. 259) have shown that farther inland it is progressively
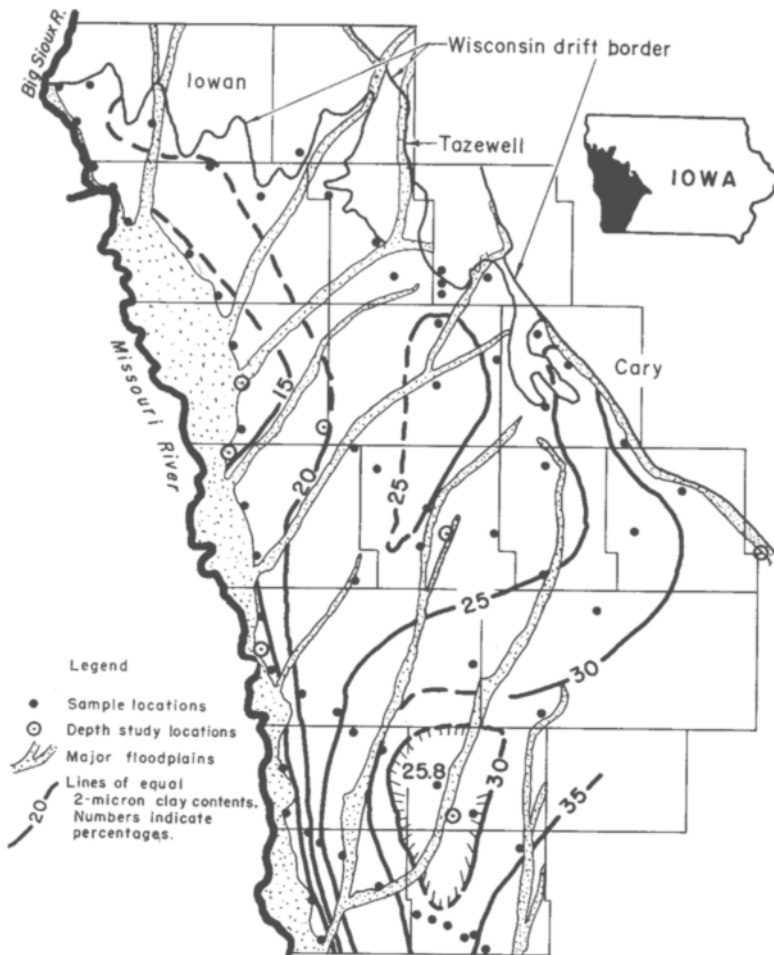

FIGURE 1. — Tentative map showing areal distribution of clay contents in the Wisconsin loess of southwestern Iowa. Partly after Iowa Geological Survey.

TABLE 1.— FIELD INFORMATION ON THE LOESS SAMPLES SELECTED FOR DETAILED STUDY.

Sample No.	Age classification	Sampling depth[2] ft.	Location		Twp. North	Range West	Soil series	Oxidation	Carbonates
			County	Section					
55-1[1]	Upper Wisconsin	2½-3½	Harrison	SW/c, S-8	81	44	Hamburg	Oxidized	Calcareous
20-2[1]	Wisconsin (undifferentiated)	39-40	Harrison	S-15[3]	78	43	Hamburg	Oxidized	Calcareous
61-2	"	17-18	Ida	NW¼,S-9	87	40	Monona	Oxidized	Calcareous
26-1[1]	"	4-5	Shelby	SE¼,S-21	81	40	Monona	Oxidized	Leached
26-2	"	10-11	Shelby	SE¼,S-21	81	40	Monona	Unoxidized	Calcareous
29-1	"	5-6	Audobon	NW/c,SW¼,S-13	78	36	Marshall	Oxidized	Leached
36-1	"	5½-6½	Montgomery	SE¼,NE¼,S-14	72	38	Marshall	Oxidized	Leached
43½-1[1]	"	5-6	Fremont	NW/c,S-36	68	40	Marshall	Oxidized	Leached
46-1	"	5-6	Page	NW¼,S-30	67	37	Marshall	Oxidized	Leached

[1] These samples were selected for petrographic analysis.
[2] Measurements are from the earth's surface.
[3] Sampled from the bluff behind the third ward school in Missouri Valley, Iowa.

lower in calcium carbonate, decreasing from 12 or 14 percent near the river to about 1 percent inland. Smith (1942, p. 164 f.) suggests that this is due to leaching during deposition, and that farther inland where the loess is thinner it was necessarily deposited more slowly, and leaching was greater. Recently it was suggested (Ruhe and Riecken, 1953) that increased weathering away from the river is caused by the overlapping of the Brady weathering and Recent weathering inland where the Upper Wisconsin (Bignell) loess which separates these profile developments is presumably thin or absent. Unpublished work by the authors (Handy, 1953, p. 110) shows that the surface area of quartz grains relative to other minerals in the plus 5 micron fraction of the loess increases with increasing clay content, and that the heavy mineral percentages decrease with increasing percent of clay. Both of these relationships suggest that high clay contents in the loess are related to increased weathering, in addition to distance from the source.

Selection of Samples

During preliminary studies, the Wisconsin loess in southwestern Iowa was traversed and sampled at a constant depth to show areal variations, and at varying depths at a number of locations to show variations with depth. Most of the available data have been reported (Davidson and Handy, 1952; Davidson, Handy, and Chu, 1953) or summarized (Handy, 1953), and the sampling system is shown in Figure 1.

Eight of the loess samples obtained during the preliminary studies were selected for detailed study. These samples cover the entire range of clay contents found in the preliminary samples, and on the basis of test data
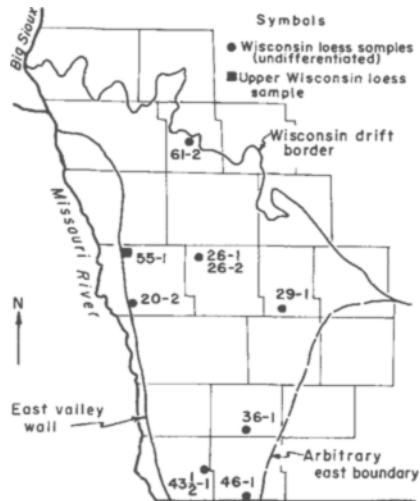

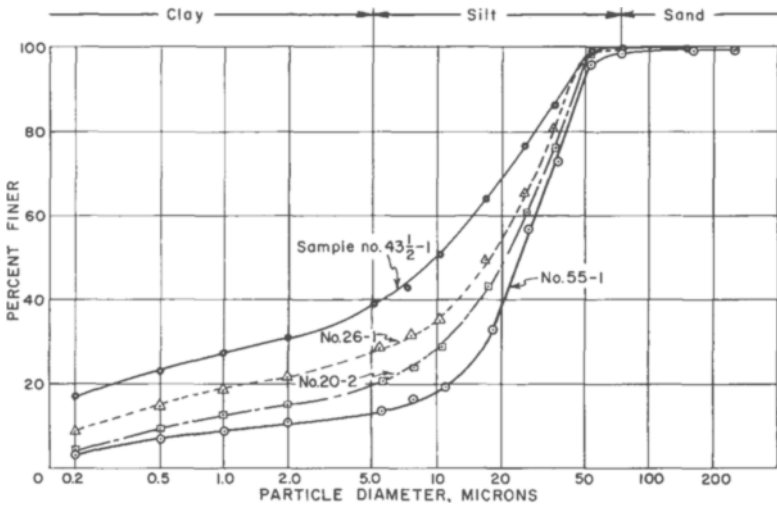FIGURE 2. — Wisconsin loess samples selected for detailed study.

FIGURE 3. — Particle-size distributions of four Wisconsin loess samples. Curves for other samples are similar.

are representative of them. An additional sample (no. 26-2) was taken deeper in the section at one of the locations to show any compositional variations related to the oxidation condition. The field locations and descriptions of the samples are given in Table 1. The approximate locations are shown in Figure 2. Four of these samples (55-1, 20-2, 26-1 and 43½-1) were subjected to more complete petrographic analysis (Handy, 1953).

COMPOSITION OF CLAY IN THE LOESS

Particle Sizes

Particle-size distribution curves for four of the loess samples are shown in Figure 3. Curves for all other Wisconsin loess samples taken in the preliminary studies are similar to these and in general fall within the range represented. Particle-size curves for the clay range of the nine selected samples are presented in Figure 4.

The mechanical analyses were performed by sieving, and for particle sizes down to 5 microns they were done by the hydrometer method (A.S.T.M. method D422-39) (A.S.T.M., 1950, p. 45) as modified by Davidson and Chu (1952), using sodium metaphosphate as a dispersing agent. Determinations in the 0.2 to 5 micron range were made by a pipette method employing gravity settling as described by Handy and Davidson (1953).

The similarity in shape of the particle-size curves in the clay range is noteworthy and suggests a similarity in clay mineral composition. The
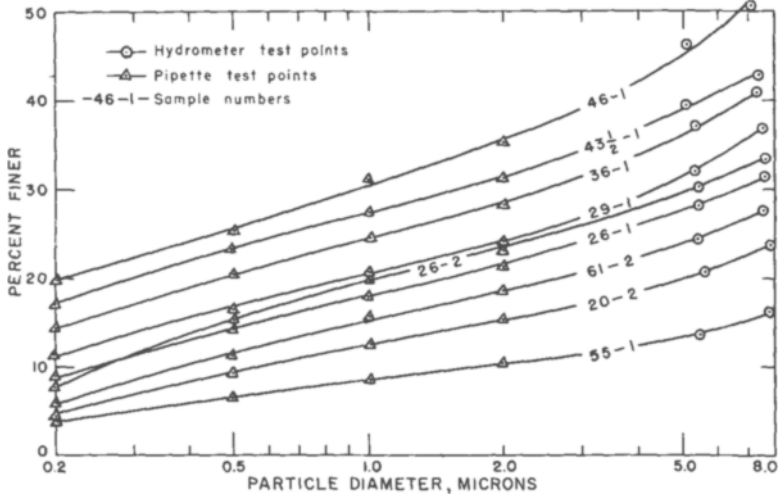
FIGURE 4. — Particle-size distributions in the clay range of selected Wisconsin loess samples.

curve for the unoxidized sample, 26-2, dips within the fine-clay range. If this lower proportion of fine clay is not due to a difference in clay mineral related to the oxidation condition, it may be due to poorer dispersion caused by the presence of relatively soluble ferrous ions, or to a smaller amount of colloidal ferric oxide in the fine clay fraction.

Differential Thermal Analysis

Differential thermal curves for material representative of the minus 2 micron clay fractions of the selected loess samples are presented in Figure 5. The clay material was separated by sedimentation based on the layer principle as described by Chu, Davidson, and Sheeler (1954). Curves showing identical but smaller reactions were obtained for minus 0.2 micron and 0.2 to 5 micron fractions of some samples, and also for whole, untreated samples. This would indicate that the same clay minerals exist in the minus 0.2 micron material as in coarser fractions. The large interlayer water reaction below 200° indicates a montmorillonite-group mineral. The endothermic reaction between 500° and 600°C is characteristic of illite or nontronite; the endothermic reaction apparent in some cases between 600 and 700°C probably indicates montmorillonite-group minerals. Chemical and petrographic data on the whole loess sample (Handy, Davidson, and Chu, 1954) indicate that iron occurs in the clay fraction, but not in quantity sufficient to suggest nontronite as the montmorillonite-group mineral. The iron content of the minus 2 micron clay fraction is high enough (maximum about 10 or 15 percent Fe_2O_3) to suggest an iron-rich beidellite.
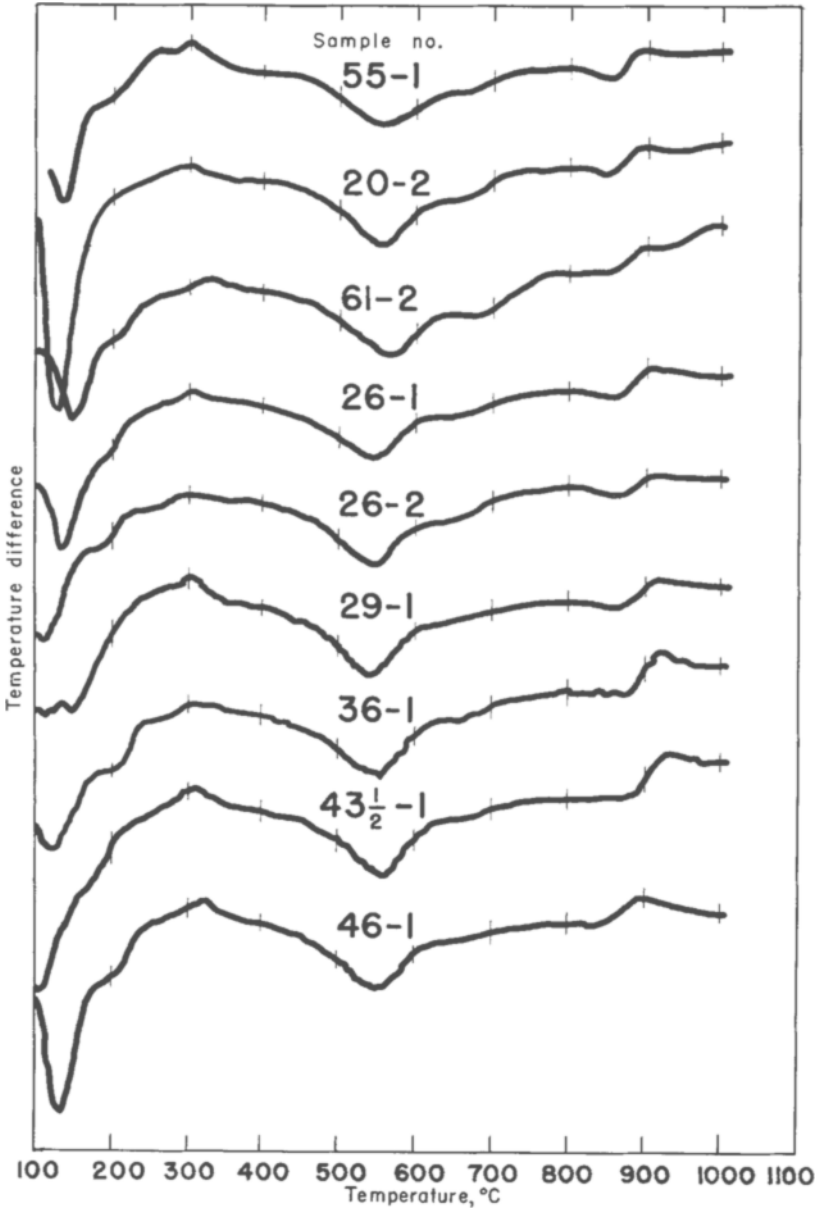
Figure 5. — Differential thermal curves for minus 2-micron clay material in selected Wisconsin loess samples.

Differential thermal analysis data on whole loess samples indicate that the clay mineral composition may be rather uniform over the southwestern Iowa area (Davidson and Handy, 1952, p. 262) and through the A and B horizons. Thermal curves for representative soil series and underlying loess are shown in Figure 6. In most cases the A horizon shows a very large organic matter reaction, a large quartz reaction, and a small or absent clay mineral reaction. Other curves in the figure represent B and C horizons, and loess which is oxidized or unoxidized, calcareous or leached. In all cases the clay mineral reaction appears to be the same, indicating montmorillonite and illite.

Cation Exchange

Cation-exchange capacities of the minus 2 micron clay fractions of samples whose locations are shown in Figure 2 were determined by an ammonium acetate method and reported by Davidson and Sheeler (1953). The exchange values are shown in Table 2, and being relatively high, they probably indicate the presence of montmorillonite-group minerals.

TABLE 2. — RESULTS OF CATION EXCHANGE CAPACITY TESTS ON THE MINUS 2 MICRON CLAY FRACTIONS OF THE SELECTED LOESS SAMPLES.

Sample No.	Cat. Exch. Cap., meq/100 g
55-1	59.3
20-2	58.6
61-2	52.5
26-1	62.8
26-2	59.0
29-1	62.2
36-1	63.1
43½-1	59.9
46-1	57.4

Determinations of the kinds of exchangeable cations were made with a flame photometer on four whole loess samples. These data are given in Table 3, with other chemical data for comparison. In all four samples the principal exchangeable cation appears to be calcium, even though two of the samples have low carbonate contents and would be described in the field as leached. Calcium and magnesium were not separated in the ion determinations, but a spot test (Lambe, 1951) failed to show the presence of any magnesium.

TABLE 3. — CHEMICAL DATA ON FOUR LOESS SAMPLES.

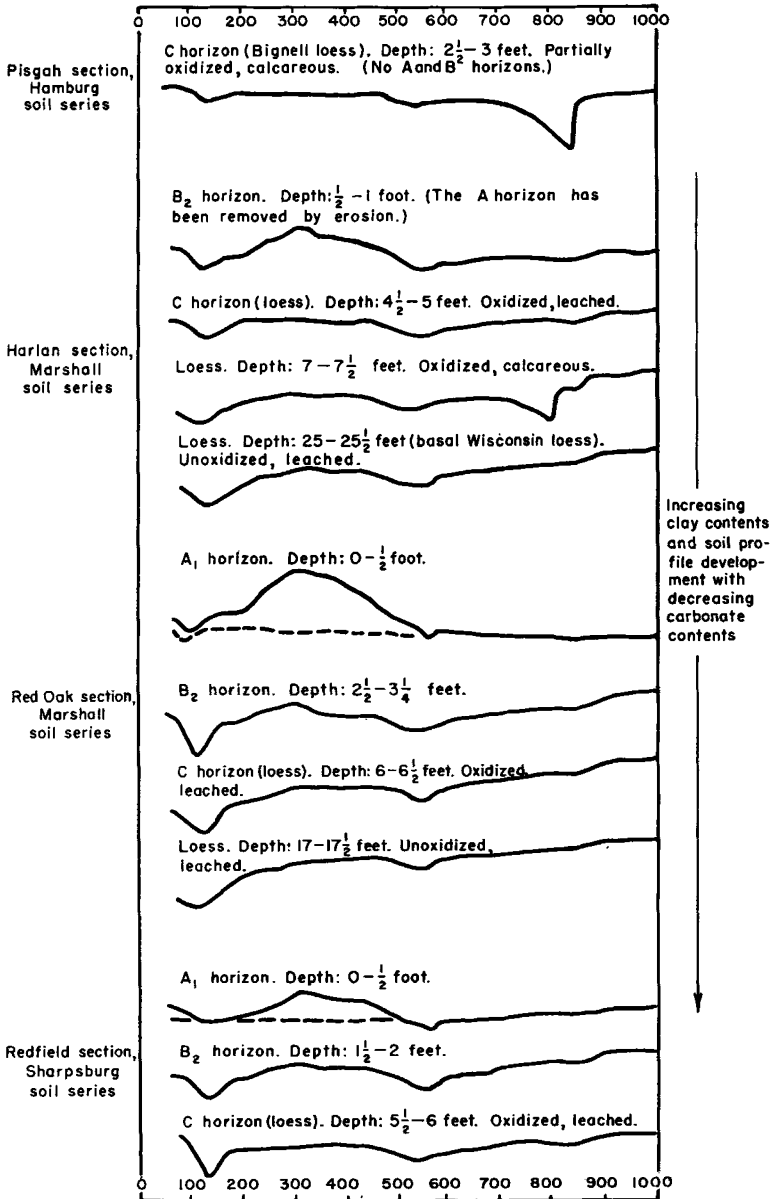| Sample No.	Cat. Exch. Cap., meq/100g	Exch. Cations, meq/100g			pH	CaCO₃ percent	Organic Matter percent
		Na	K	Ca,Mg			
55-1	11.2	1.4	2.0	7.8	8.35	10.34	0.24
20-2	13.4	1.5	1.6	10.3	8.7	9.35	0.17
26-1	18.2	0.9	1.2	16.1	7.0	1.89	0.18
43½-1	24.4	1.3	1.3	21.8	6.7	1.60	0.37

FIGURE 6. — Differential thermal curves for whole loess and soil samples in soil series from west to east in southwestern Iowa. Dotted lines indicate prior removal of organic matter.

Optical Tests and Staining

Determinations of refractive index, made with mixtures of n-butyl phthalate and α chloronaphthalene, indicate γ values of between 1.550 and 1.555 for minus 2 micron clay oriented aggregates. Interference figures are weak and show a biaxially negative optical orientation with a low 2 V. On the basis of these tests alone, the clays might be identified as a montmorillonite mineral or as a mixture of minerals.

Staining tests were performed on four of the loess samples by methods used by Mielenz and others (Mielenz and King, 1951). Three complementary tests, with malachite green, safranine Y, and benzidine, were used. All tests indicated montmorillonite as the major clay mineral.

X-ray Data

X-ray analyses have been performed on four of the loess clay fractions. The analyses were made by R. E. Grim on minus 2 micron clay materials submitted to him. Dr. Grim's interpretations of the data are summarized in Table 4 (Grim, personal communication, September 22, 1953).

The samples are arranged in the table in the order of increasing clay contents. The x-ray data indicate that the clay minerals in the loess samples are largely montmorillonite and illite, and indicate that montmorillonite predominates in most of the samples. The x-ray data show montmorillonite content variations which are not revealed by the other test data. By indicating increasing montmorillonite with increasing clay contents, the x-ray studies tend to confirm that weathering is progressively greater in the loess with increased clay contents. The sample with the lowest montmorillonite and the highest illite content, no. 55-1, is of probable Upper Wisconsin (Bignell) age, and the other samples are of probable Lower Wisconsin age.

TABLE 4. — INTERPRETATIONS OF X-RAY ANALYSES ON MINUS 2 MICRON CLAY MATERIAL FROM FOUR SELECTED WISCONSIN LOESS SAMPLES.[1]

Sample No.	Montmorillonite	Illite	Kaolinite	Quartz
55-1	Abundant	Almost equal to montmorillonite	Small amount	About 10%
20-2	Abundant	About 1/3 the abundance of montmorillonite	Trace ?	About 10%
26-1	Abundant	Slightly less than in 20-2	Small amount	About 10%
43½-1	Sample is largely montmorillonite	Contains very little illite	——	About 10%

[1] Analyses and interpretations by R. E. Grim.

Identification of Clay Minerals — Summary

Tests to date indicate montmorillonite and illite are the principal clay minerals in the loess. The lack of any difference in clay mineral with particle size, the indistinct optical properties, and the predominance of the illite thermal reaction when other tests indicate the presence of montmorillonite; all tend to indicate a randomly interstratified mixture of montmorillonite and illite (Grim, 1953, p. 246, 289).

OCCURRENCE OF CLAY IN THE LOESS

Of particular importance from an engineering point of view is the mode of occurrence of clay in the loess. Thin sections were found to be less satisfactory for such a study than simple grain mounts of whole, untreated samples. Worthy of mention here is the pioneer work of Kubiena (1938, p. 76, 129-153) in this field. Such grain mounts are designated by him as "debris preparation" (Trümmerpräparat), and the relations between individual particles as "elementary fabric" (Elementarge-füge). The elementary fabric in a soil is not destroyed by mechanical breaking or crushing.

Clay particles in the loess were found to occur in two distinct kinds of coatings on larger silt grains. These types are:

1. Minute greenish specks adhering either individually or in clusters to a host grain. The shapes of these clay particles are not resolved by a polarizing microscope. The speck clay coatings are shown in Plate 1.

2. Continuous,, greenish, birefringent coatings partially covering the surfaces of larger grains. Grains with these coatings are less common than those with the speck coatings, but the area covered is much greater. The continuous coatings are commonly visible only around the edges of the host grain, as shown in Plate 2. The lower photomicrograph from a polarizing microscope with crossed Nicol prisms shows the host grain turned to a position of extinction to show the birefringent clay coating. Since clay mineral grains are highly birefringent only when viewed on edge, they are apparently oriented flat against the host grain.

Continuous clay coatings have been observed in thin sections of loess by Swineford and Frye (1951) and Holland and King (1949). From staining tests the latter identified the clay mineral as montmorillonite. Staining tests in the present study also indicated the coatings to be montmorillonite, but it is probable that they are a mixed-layer clay mineral, as previously discussed.

It should be mentioned that noticeable amounts of both types of clay coatings persisted on the host grains through a vigorous dispersion treatment (4 minutes in a malted-milk mixer type apparatus). In sample 43½-1, which has the highest clay content of the four loess samples studied, clay also occurs as separate particles and as large aggregates which are dominantly clay.
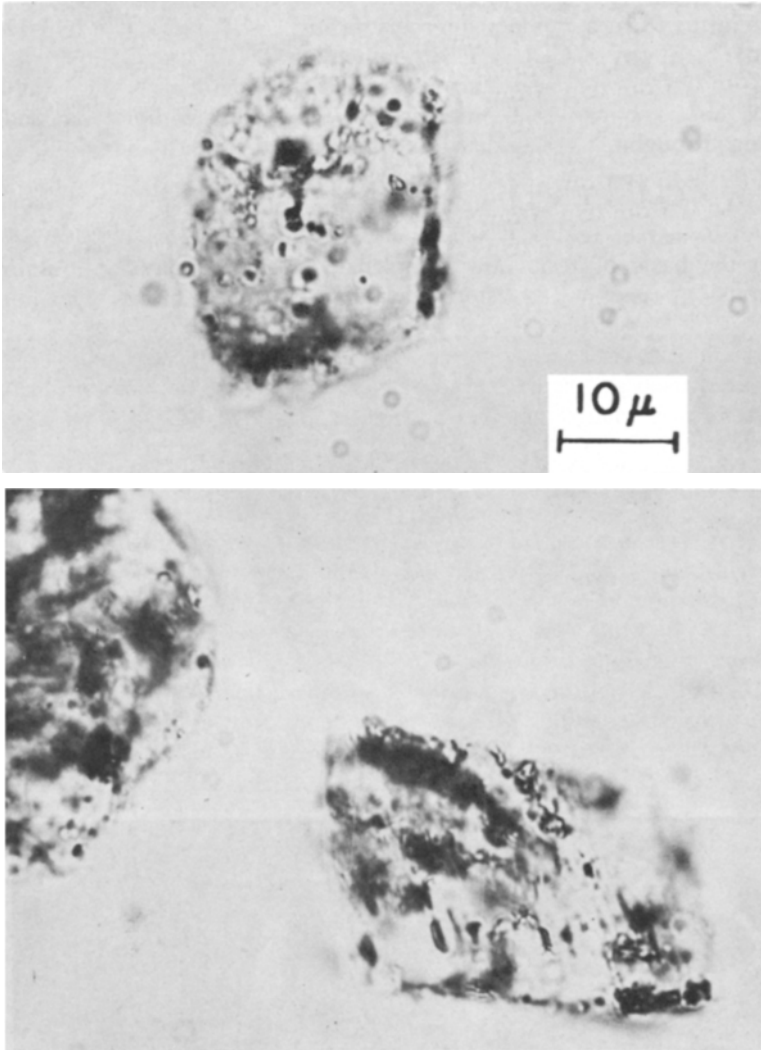
PLATE 1. — Photomicrographs of loess grains with particles of clay adhering.

Occurrence of Clay:

Discussion

The occurrence of clay in the loess as coatings, particularly as continuous coatings, indicates that the present disposition of much of the clay is certainly secondary. This might be brought about by weathering or such attendant conditions as alternate wetting and drying (which would

also tend to form a random interstratification of the clay minerals). The lack of large variations in the clay-mineral composition of the loess, even through the various soil horizons, would indicate a certain equilibrium under present conditions down through the A and B horizons, and extending throughout the oxidized and unoxidized loess.

CONCLUSIONS AND RELATIONSHIPS TO ENGINEERING PROPERTIES

On the basis of tests now completed, the major clay mineral in the Wisconsin loess of southwestern Iowa appears to be a mixed-layer mineral
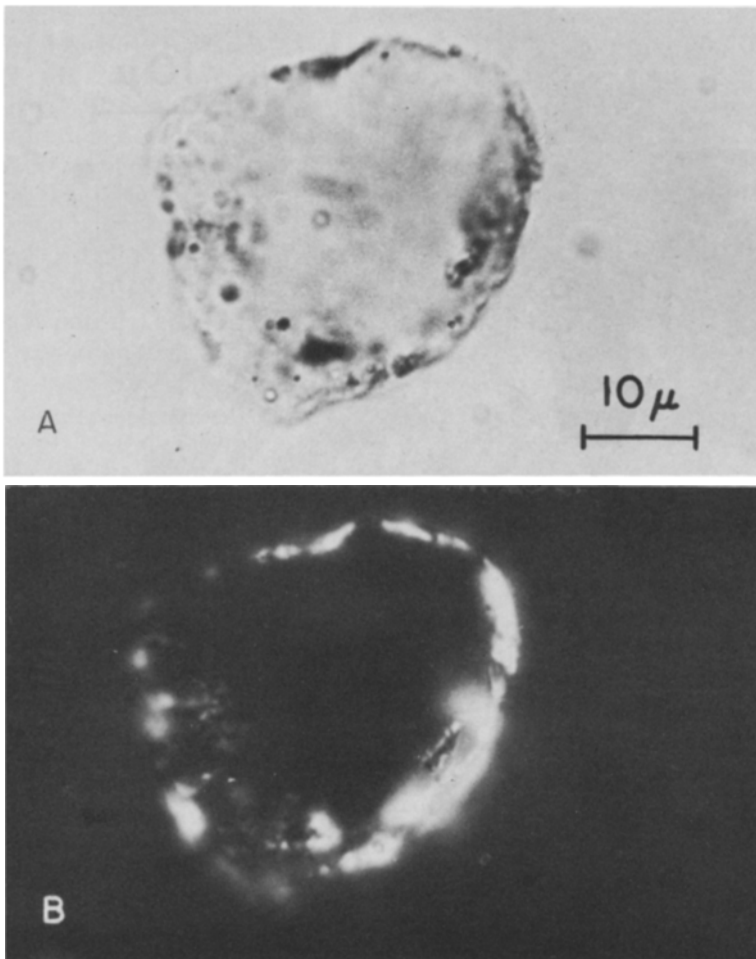
PLATE 2. — Continuous clay coatings on a loess grain. (A) under plane polarized light; (B) under crossed Nicols.

of montmorillonite and illite. Studies also indicate that the percent of clay in the loess varies greatly, and that the composition of the clay fraction varies gradually, depending on the clay content.

This apparent uniformity in the clay mineral composition in the loess is reflected in the effect of percent clay on various engineering properties. These relationships are linear, and have been discussed by Davidson and Sheeler (1952). Selected graphs are presented in Figures 7, 8, 9, 10, and 11. The scattering of points may be due to experimental error and minor differences in clay mineral composition.

Plastic Limit

The relationship between loess clay content and plastic limit is of particular interest, since it is the reverse of that which has been reported. As shown in Figure 8, with increasing clay contents there is a decrease in the plastic limit. The reverse trend is reported by Baver (1948, p. 116f.) for a clay soil with additions of various amounts of silt. Theoretically, the plastic limit represents the moisture content at which cohesion is a maximum, and the water is oriented and held by the clay particles (Terzaghi, 1926, p. 154). Additional water is not strongly adsorbed and serves as a lubricant. Therefore an increase in the clay content should cause more water to be adsorbed, increasing the plastic limit.

A possible explanation for the trend in plastic limit shown by the loess is related to the test itself, which has long been criticized. Essentially, the plastic limit test is performed by repeatedly rolling a moistened soil specimen into a thread $\frac{1}{8}$ inch in diameter until the thread is dry enough
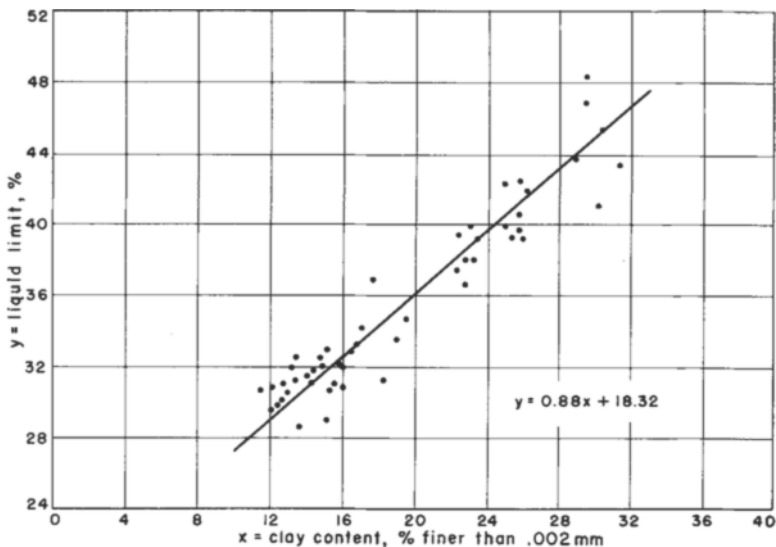

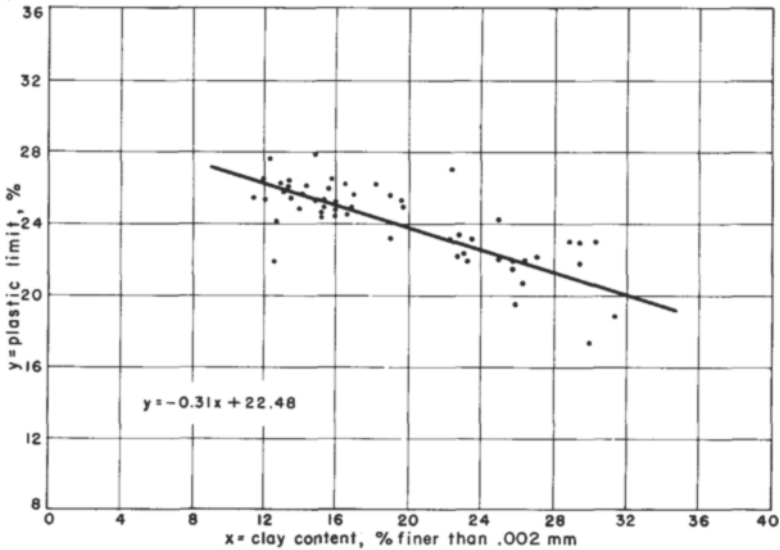FIGURE 7. — Relation of clay content to liquid limit.

FIGURE 8. — Relation of clay content to plastic limit.

that it crumbles. The moisture content at this point is defined as the plastic limit. The rolling is done with the palm of the hand, usually on a glass plate.

With loess low in clay, the cohesive forces holding the rolled thread together are small, and the pressure applied by the hand must be slight or the thread will smear. The forces holding the thread together at the plastic limit are probably mainly due to apparent cohesion caused by the surface tension of water between the grains. At a lower moisture content true cohesive forces involving the clay grains would be developed, but much of the apparent cohesion would be lost, and the two would add up to less. Therefore, the plastic limit, or point of maximum cohesion, tends to be greater for a loess low in clay than for one high in clay.

With higher clay contents in the loess, considerable cohesion is developed, and a comparatively large pressure is required to roll the specimen out into a thin thread. This probably results in a more efficient use of the water, and the effect of apparent cohesion gives way to true cohesive forces. It should be pointed out that most of the clay contents investigated for plasticity by Baver are considerably higher (37 to 87 percent 5 micron clay) than those in the southwestern Iowa loess; and with higher clay contents in the loess, as in southern Iowa, the line in Figure 8 may curve upward. Baver's data show such a change in slope, the plastic limit increasing only slightly from 37 to 53 percent clay, then increasing rapidly up to 87 percent clay. His plasticity index for the 87 percent clay soil is 70 — 30 = 40. No information is given on the clay minerals present.
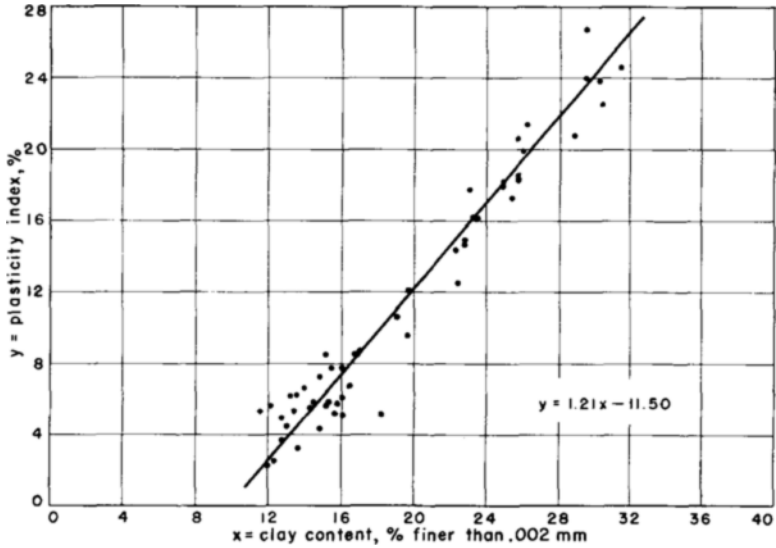
FIGURE 9. — Relation of clay content to plasticity index.

The possibility that the variations in the clay mineral composition found in the loess may affect plasticity should also be considered. As pointed out by Grim (1948, p. 11), even small amounts of interlayered montmorillonite greatly influence the plasticity of a clay, since the montmorillonite
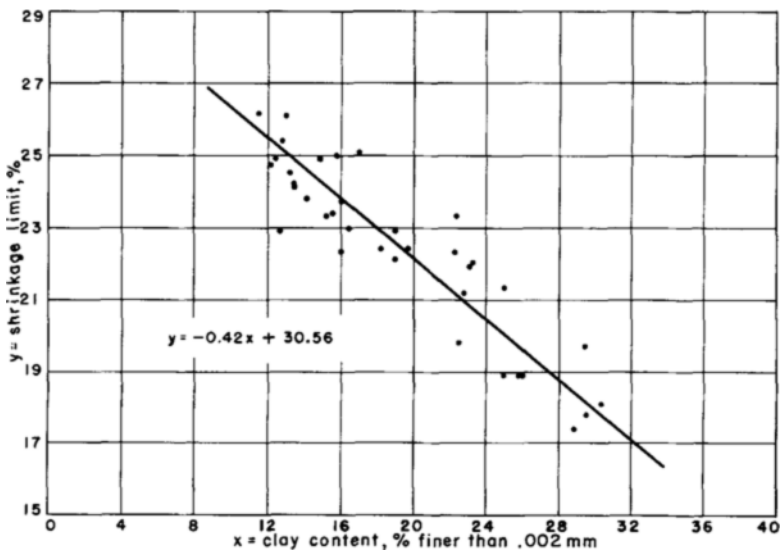
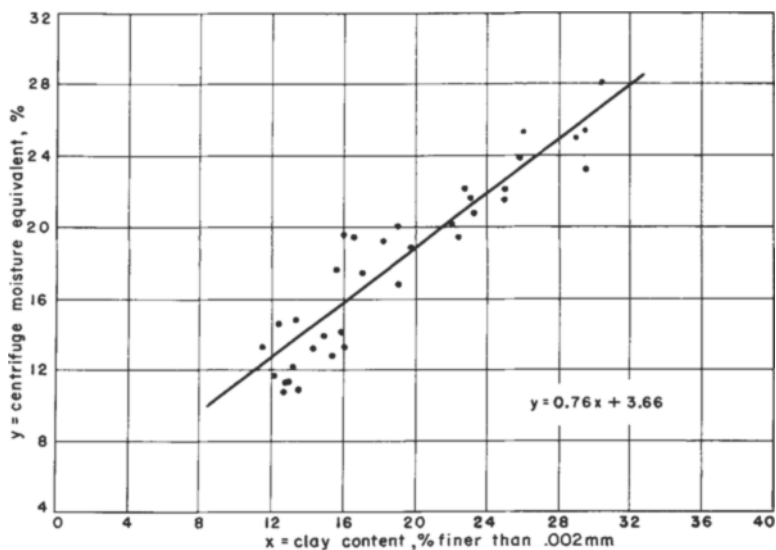

FIGURE 10. — Relation of clay content to shrinkage limit.

FIGURE 11. — Relation of clay content to centrifuge moisture equivalent.

forms planes of weakness in the interlayer system. Therefore, above a certain amount a further increase in the proportion of interlayered mont-morillonite probably does not greatly affect the plasticity, since many glide planes are already present. Therefore, variations in the relatively high proportion of montmorillonite in the clay fraction of the loess may have little effect on the plasticity.
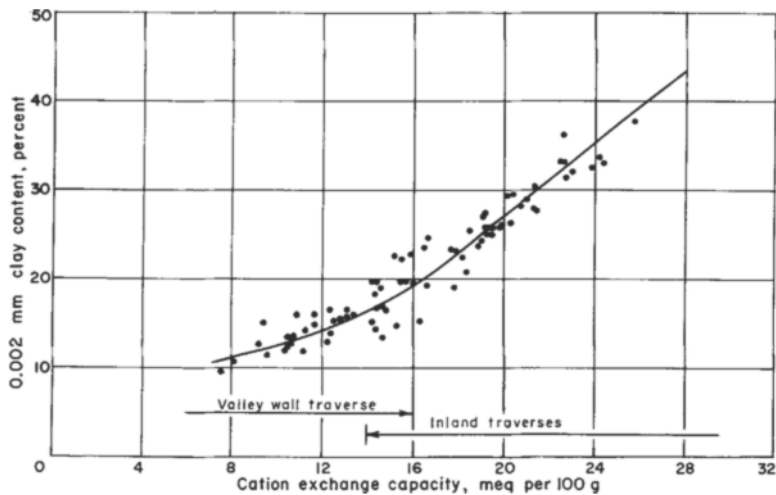

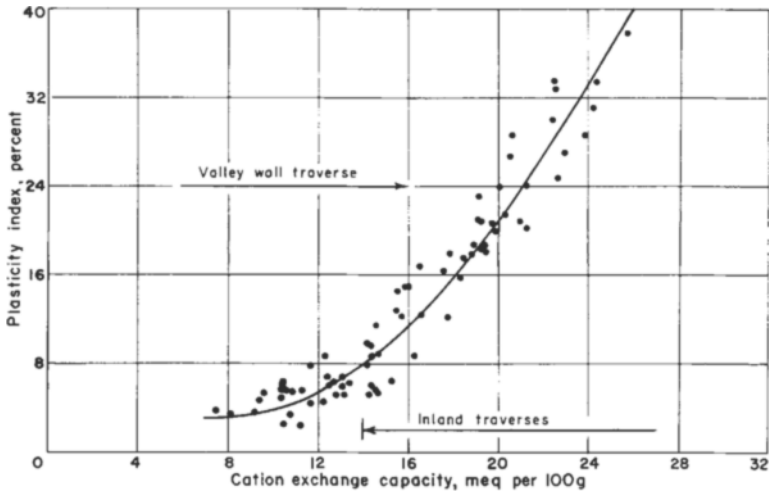FIGURE 12. — Relation of cation-exchange capacity to 0.002 mm clay content.

FIGURE 13. — Relation of cation-exchange capacity to plasticity index.

Cation-Exchange Capacity

The correlation between cation-exchange capacity of the whole loess and various properties has also been discussed (Davidson and Sheeler, 1952), and example graphs are presented in Figures 12 and 13. These relationships are not linear, probably because of the effect of calcium carbonate on the cation-exchange capacity. The presence of carbonates appears to reduce the cation-exchange capacity as measured in the whole loess. In general, high carbonate content in the loess is associated with low clay content.

ACKNOWLEDGMENT

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