CLAY MINERALS IN SOME ILLINOIS SOILS DEVELOPED FROM LOESS AND TILL UNDER GRASS VEGETATION

A. H. Beavers, W. D. Johns, R. E. Grim, and R. T. Odell
University of Illinois

ABSTRACT

Clay mineral analyses were made of three groups of soil profiles — one developed from Peorian loess overlying Illinoian till — one associated with glacial till of Wisconsin age — one developed on deep to thin loess overlying Wisconsin till. These groups were investigated to determine the influence of parent material and intensity of weathering upon the soil profile development and clay mineral composition.

Montmorillonite, illite, and chlorite are the dominant clay minerals in all the samples studied. In known loess samples, montmorillonite is invariably the most abundant clay mineral component. In the samples of unweathered till of Wisconsin age, illite and chlorite are the abundant clay minerals.

INTRODUCTION

The soils of Illinois have developed primarily from loess and from glacial till of Wisconsin age. Nearly 70 percent of the soils have either developed entirely from loess or have been strongly influenced by it in their development, depending upon the thickness of the loess mantle (Fig. 1, Group I). Loess is thicker and coarser near the major rivers in Illinois, and according to Smith (1942), the rate of thinning and the decrease in mean particle size of the loess vary (within limits) logarithmically with the distance from the river bluffs along the major streams. The largest area of soils in Illinois which developed primarily from glacial drift is in the northeastern one-quarter of the state where the loess cover on glacial drift of Wisconsin age (Fig. 1, Group II) is very thin or absent.

The purpose of this study was to determine (a) the kind and relative amount of various clay minerals in soils that represent six degrees of weathering in Peorian loess, (b) the kind and amount of clay minerals in soils associated with six textural classes of glacial till of Wisconsin age, and (c) whether differences in clay minerals in each soil profile are due to soil development or are inherited from different parent materials or both. Another specific objective (d) was to compare the types of clay minerals in the calcareous Peorian loess with those found in the calcareous till of Wisconsin age. This was done to test the generally accepted concept that all size fractions of the Peorian loess in Illinois, including clay, are a wind deposit which emanated from the flood plains of the major nearby rivers that carried melt waters and variable textured sediments from the glacial drifts of Wisconsin age.

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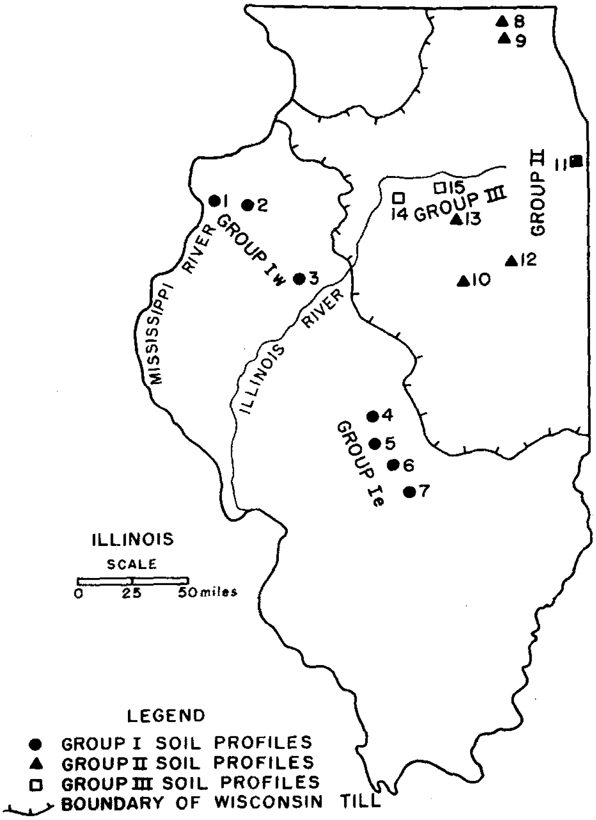

FIGURE 1. — Location of soil profiles selected for clay mineral analyses.

REVIEW OF LITERATURE

In 1930, Allen suggested the presence of what he called beidellite clay in soils developed from loess.

From a chemical study of soils representing five successive stages of development in Peorian loess (now divided into six different stages of development), Bray (1934) concluded that the predominant clay mineral was beidellite. He also concluded that the increased concentration of clay in the B horizon of these soils was a result of eluviation of the finer clay material from the A horizon. In two other papers Bray (1935, 1936) reported the chemical and physical changes in soil colloids with advancing development and the weathering loss of K and Mg. In these papers he included results on Clarence silt loam, a soil developed primarily from clay till of Wisconsin glacial age. From the chemical analyses he estimated that the calcareous Wisconsin till, or C horizon of Clarence, contained 61 percent illite in the clay $<0.06\ \mu$, 67 percent in the 0.1-0.06 μ clay, and 70 percent in the 1.0-

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0.1 μ clay fraction. In the same study Bray calculated, on the basis of chemical analyses, that the C horizon of soils developed from Peorian loess contained 8 to 11 percent illite in the clay $<0.06\ \mu$, 13 to 18 percent illite in the clay 0.1-0.06 μ, and 17 to 24 percent illite in the clay 1.0-0.1 μ. The illite content of the B horizon of the Clarence and the loessial soils was equal to or slightly less than the illite content of their respective C horizons. Although these estimates of the kind and amount of various clay minerals were based on chemical analyses, they show that the clays in the Peorian loess differ markedly from those in calcareous till of Wisconsin age.

From an X-ray, chemical, and petrographical study of soils developed from Peorian loess in Illinois, Grim, Bray, and Bradley (unpublished work) found that the predominant clay mineral in the finer clay fractions of these loessial soils was of the montmorillonitic type, whereas illite was one of the major constituents in the coarse clay fraction.

SAMPLES STUDIED

The following three groups of soil profiles were selected for this study:

Group I — soils that represent six stages of development in Peorian loess overlying Illinoian till,

Group II — soils that have developed from six textural classes of calcareous glacial till of Wisconsin age where the loess cover is thin or absent, and

Group III — soils that have developed from deep to thin Peorian loess over calcareous silty clay loam glacial till of Wisconsin age.

All of the soils included in this study in Groups I, II, and III developed under grass vegetation on gentle to moderate slopes.

The six successive stages of development in soils from Peorian loess are represented by silt loam types of the Joy, Muscatine, Ipava, Herrick, Cowden, and Cisne series which are listed in the order of increased maturity. The stage of development of Group I soils along the northwest-southeast traverse in Figure 1 is a reflection of the loess depth, particle size distribution in the loess, and the amount of weathering during and since the period of loess deposition. The clay content of the B horizons of Group I soils increases with increased development from 21.8 percent clay in the B horizon of Joy to 46.0 percent in Cisne (Table I). Joy, Muscatine, and Ipava are Brunizems; Herrick is a Planosol intergrade to Brunizem; and Cowden and Cisne are Planosols. The Joy (1)*, Muscatine (2), and Ipava (3) soils were sampled west of the Illinois river and are referred to as Group Iw. The Ipava (4), Herrick (5), Cowden (6), and Cisne (7) soils which were sampled east of the Illinois river are referred to as Group Ie. Two Ipava silt loams were selected to study the influence of the Illinois river as a loess source on the clay mineral composition of this soil. The Ipava (3), located west of the Illinois river, is believed to have developed

* Numbers refer to profiles in Tables I, II, and III.

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Table I. — Selected Physical and Chemical Analyses of Soils Studied

		Group I soils developed from loess over Illinoian till							Group II soils developed primarily from Wisconsin till						Group III soils developed from thick to thin loess on Wisconsin till		
Profile number		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	11
Soil series		Joy	Muscatine	Ipava	Ipava	Herrick	Cowden	Cisne	Warsaw	Ringwood	Saybrook	Elliott	Swygert	Clarence	Muscatine	Tonica	Elliott[1]
A horizon																	
Depth	in.	0–19	0–19	0–17	0–23	0–18	0–16	0–19	0–10	0–11	0–17	0–12	0–11	0–8	0–21	0–18	
Depth of layer analyzed	in.	0–7	0–5	0–6	2–6	2–5	0–6	0–8	0–5	0–4	0–11	0–7	0–8	1–6	0–16	0–13	
Lab. number of layer analyzed		15873	15886	13873	16735	16760	14075	14083	17612	17595	17775	17504	17790	17740	17806	17798	
Cation exchange capacity	me./100 gm.	17.3	24.6	31.8	20.2	19.9	16.4	10.7	23.8	21.2	27.2	28.6	27.6	25.6	—	—	
Percent base saturation	percent	—	71	81	92	92	76	28	100	100	—	81	—	92	—	—	
pH		5.3	5.1	5.5	5.9	6.0	5.5	4.4	7.7	7.3	7.3	5.9	6.3	6.5	5.8	6.9	
Organic carbon	percent	3.26	3.53	3.13	2.66	2.37	2.35	1.51	2.98	3.56	2.65	4.15	3.36	3.96	2.56	2.61	
Sand, 2.0–0.05 mm.[2]	percent	1.7	1.3	1.6	1.5	3.2	5.2	5.6	9.9	28.1	5.0	11.9	4.6	3.4	1.0	1.1	
Clay, < 0.002 mm.[2]	percent	17.8	23.7	29.0	24.9	20.8	17.4	17.7	23.5	18.0	29.3	32.1	32.2	33.0	20.3	22.7	
B horizon																	
Depth	in.	19–47	19–40	17–36	23–44	18–42	16–49	19–46	10–25	11–34	17–35	12–24	11–27	8–15	21–47	18–40	
Depth of layer analyzed	in.	24–29	25–27	17–23	27–29	21–23	22–30	21–31	19–25	17–25	21–28	21–24	18–23	11–15	25–36	21–33	
Lab. number of layer analyzed		15877	15894	13877	16744	16767	14079	14086	17616	17599	17778	17508	17794	17743	17809	17801	
Cation exchange capacity	me./100 gm.	16.5	25.8	34.6	25.3	28.8	29.5	28.3	20.4	12.8	28.8	14.8	20.8	22.6	—	—	
Percent base saturation	percent	—	82	—	88	83	94	39	77	89	—	100+	—	100+	—	—	
pH		5.5	5.3	5.5	5.7	5.1	7.2	4.4	5.5	6.2	5.7	7.1	6.4	7.1	5.3	5.4	
Organic carbon	percent	.93	.96	1.39	.93	.97	.60	.53	.51	.67	.91	.68	1.28	.91	.77	.54	
Sand, 2.0–0.05 mm.[2]	percent	.8	1.8	.8	.6	1.5	2.3	2.8	12.5	46.6	5.4	10.5	6.1	1.1	1.0	1.6	
Clay, < 0.002 mm.[2]	percent	21.8	34.5	39.8	38.2	41.8	44.7	46.0	27.1	21.3	39.0	46.8	49.4	70.4	28.4	29.1	
C horizon																	
Depth	in.	47–80+	40–152	36–63+	44–73	42–57	49–62	46–56	29–50+	34–48+	35–50	24–43+	27–40+	15–50	47–82	40–52	
Depth of layer analyzed	in.	69–75	95–104	51–63	61–66	49–53	49–62	46–53	40–50	34–48	35–50	38–43	31–40	24–32	53–68	45–52	
Lab. number of layer analyzed		15884	15904	13882	16755	16777	14082	14089	17619[3]	17602	17780	17511	17797	17745	17812	17804	
Cation exchange capacity	me./100 gm.	11.0	13.3	12.6	—	16.0	13.2	20.7	—	—	—	—	—	—	—	—	
Percent base saturation	percent	Calc.	Calc.	Calc.	Calc.	100+	100+	69	Calc.	Calc.	Calc.	Calc.	Calc.	Calc.	Calc.	Calc.	
pH		7.7	7.7	7.8	6.5	6.0	7.7	5.0	8.3	8.2	7.9	8.0	8.0	7.9	7.9	8.0	
Organic carbon	percent	—	.18	.09	—	—	.17	.24	.18	.23	—	.47	—	.75	—	—	
Sand, 2.0–0.05 mm.[2]	percent	2.1	1.2	.8	.2	1.9	2.3	5.6	59.6[4]	41.4[4]	14.7	18.2	5.9	.6	2.0	2.5	
Clay, < 0.002 mm.[2]	percent	13.2	16.4	17.0	14.7	24.3	20.4	30.6	2.8[4]	8.2[4]	20.9	31.1	34.4	59.6	14.2	13.1	
D horizon[5]																	
Depth	in.	—	—	—	—	—	—	—	—	—	—	—	—	—	82–92+	52–64+	
Depth of layer analyzed	in.	—	—	—	—	—	—	—	—	—	—	—	—	—	82–92	54–64	
Lab. number of layer analyzed		—	—	—	—	—	—	—	—	—	—	—	—	—	17814	17805	
pH		—	—	—	—	—	—	—	—	—	—	—	—	—	8.0	7.9	
Sand, 2.0–0.05 mm.[2]	percent	—	—	—	—	—	—	—	—	—	—	—	—	—	12.7	12.4	
Clay, < 0.002 mm.[2]	percent	—	—	—	—	—	—	—	—	—	—	—	—	—	32.1	27.8	
Total depth of loess	in.	80+	152	63+	73	57	62	56	25	17	28	< 12	14	< 6	82	52	
Depth of calcareous loess	in.	64–80+	80–114+	51–63+	53–73	0	0	0	0	0	0	0	0	0	53–82	45–52	

[1] Refer to data for Elliott (11) in Group II soils.
[2] Based upon material less than 2 mm. in diameter.
[3] According to current nomenclature this is a D horizon.
[4] This horizon of Warsaw and Ringwood contain significant amounts of material greater than 2 mm. in diameter. Of the total sample, only 17.8 percent of this horizon of Warsaw and 85.6 percent of Ringwood is less than 2 mm. in diameter.
[5] The D horizons of Muscatine (14) and Tonica (15) are calcareous glacial till as are the C horizons of Group II soils, and are especially similar to the C horizon of Elliott (11) which is of silty clay loam texture.

primarily from Mississippi river loess and Ipava (4), east of the Illinois river, has developed in loess primarily from the Illinois river.

The extent of glacial drift of Wisconsin age in Illinois is shown in Figure 1. The six profiles studied in Group II represent a wide geographic area and a wide range in texture of the glacial till. The six different textures of glacial till studied are represented by silt loam soil types of the Warsaw (8), Ringwood (9), Saybrook (10), Elliott (11), Swygert (12), and Clarence (13) series, which are listed in the order of decreasing particle size of the parent materials from gravelly loam to clay. Some loess is usually present in the upper part of the solum of Group II soils, accounting for the silt loam surface texture, but it is rarely more than two feet thick. All of the soils in Group II are Brunizems.

In Group III the three profiles studied, representing the Muscatine (14), Tonica (15), and Elliott (11) series, developed from thick (82 inches), medium (52 inches), and very thin (<12 inches) loess, respectively, over silty clay loam glacial till of Wisconsin age. The calcareous loess in both the Muscatine (14) and Tonica (15) soils represents the C horizons or parent materials of these two soils since the sola have developed from loess. The underlying calcareous, silty clay loam till is referred to as a D horizon. A comparison of the clay minerals in the C and D horizons of Muscatine (14) and Tonica (15) was made to test the generally accepted concept that all size fractions of the Peorian loess in Illinois are a wind deposit which emanated from the flood plains of the major nearby rivers that carried melt waters and variable textured sediments, including clay, from the glacial till in northeastern Illinois.

ANALYTICAL TECHNIQUES

The A_1, B_2, and C horizons of each of the 15 soil profiles were studied, and for profile Nos. 14 and 15 the D horizons were also analyzed.

The clay fraction less than 2 microns in effective diameter was prepared for X-ray spectrometer analyses by the following procedure. Twenty-five grams of soil material less than 2 mm. in diameter were shaken overnight in 400 cc. of distilled water in an end-over-end shaker. For the A horizon samples only, the organic matter was removed with hydrogen peroxide before shaking. No dispersing reagent or acid was added to any of the samples. After shaking, the $<2\ \mu$ clay fraction was removed by repeated decantations. The $<2\ \mu$ fraction was then concentrated to a thick suspension, poured on microscope slides, and allowed to air dry.

X-ray diffraction patterns were obtained by means of a recording X-ray spectrometer. Only $00l$ reflections were recorded from oriented aggregates prepared as stated above. Because of the extremely poor crystalline character of soil clays, powder diffraction techniques alone are inadequate and oriented specimens are necessary for complete and accurate identification. The utilization of oriented clay minerals, coupled with focusing conditions inherent in spectrometer techniques, greatly enhances the likelihood of making accurate and reliable clay mineral analyses of such materials.

Diffraction data were obtained from duplicate samples, one in the air-dried state and also after treatment with ethylene glycol; the other sample after ignition at 550° C. It was thus possible to reveal the presence of montmorillonite, illite, and chlorite as the major clay mineral constituents of these soil clays. The illite was identified on the basis of characteristic reflections related to a 10 Å periodicity which remained unchanged following treatment with ethylene glycol; montmorillonite as a component which expanded from 14 Å to 17 Å following such treatment; and chlorite as a component exhibiting a rational sequence of basal orders of reflection related to 14 Å. The possible presence of small amounts of kaolinite in addition to chlorite cannot be denied. However, in no case is it thought that kaolinite was a major component.

Quantitative estimates were made, based on relative intensities of diagnostic reflections in the manner described recently by Johns, Grim, and Bradley (1954). It should be emphasized that the estimates given are significant only relatively and are not absolute values. In Table II the total of the montmorillonite, illite, and chlorite for an individual sample represents approximately 80 to 90 percent of the total $<2\ \mu$ clay fraction. Figure 5 shows the spectrometer traces of the ethylene glycol-treated $<2\ \mu$ clay fraction of the Muscatine profile (14). Traces of the A, B, and C horizons typify comparable horizons of the Group I loessial soils, while the D horizon trace is characteristic of the calcareous glacial till or C horizon in Group II soils.

The physical and chemical data included in Table I were obtained by standard analytical procedures used by the University of Illinois Agronomy Department. Particle size distribution was determined by the pipette method. The total chemical analyses in Table III were made by the Illinois State Geological Survey, and their collaboration is gratefully acknowledged.

RESULTS

The type and amount of clay minerals which were determined by X-ray analyses as outlined above are given in Table II. Selected physical and chemical data which apply directly to this problem are included in Table I. Much additional physical and chemical data are available as a result of intensive research on these soils by the Agronomy Department of the University of Illinois.

Group I. — The soils of Group I developed from loess that varies in thickness from approximately 25 feet in the least weathered member, Joy silt loam (1), to about 2 to 4 feet in the most strongly weathered member, Cisne silt loam (7). The C horizons of Joy (1), Muscatine (2), and Ipava (3 and 4) are calcareous and the materials of this horizon are relatively unaltered. The C horizons of Herrick (5), Cowden (6), and Cisne (7) are progressively more weathered, with the latter soil having a pH of 5.0 and 69 percent of the exchange capacity saturated with basic ions (Table I).

TABLE II. — PERCENTAGE[1] OF VARIOUS CLAY MINERALS IN THE A, B, C, AND D HORIZONS OF SOILS IN GROUPS I, II, AND III

Profile No.	Soil series	A horizon			B horizon			C horizon			D horizon[2]		
		Montmo-rillonite pct.	Illite pct.	Chlorite pct.	Montmo-rillonite pct.	Illite pct.	Chlorite pct.	Montmo-rillonite pct.	Illite pct.	Chlorite pct.	Montmo-rillonite pct.	Illite pct.	Chlorite pct.
		Group I soils developed from loess over Illinoian till											
1	Joy	25	40	30	80	10	10	80	10	10			
2	Muscatine	45	35	20	80	10	10	75	10	20			
3	Ipava	65	25	10	90	5	5	90	5	5			
4	Ipava	30	50	20	70	20	10	55	15	30			
5	Herrick	80	10	5	80	10	10	80	10	10			
6	Cowden	35	45	20	90	5	5	70	10	20			
7	Cisne	20	45	35	90	5	5	90	5	5			
		Group II soils developed primarily from Wisconsin till											
8	Warsaw	40	35	25	90[3]	5	5	70[4]	25	5			
9	Ringwood	20	50	30	30	30	35	0	60	40			
10	Saybrook	45	35	20	90[3]	5	5	0	75	25			
11	Elliott	5	80	15	10	65	25	0	65	35			
12	Swygert	15	65	15	20	70	10	0	80	20			
13	Clarence	5	75	20	10	60	25	0	70	30			
		Group III soils developed from thick to thin loess on Wisconsin till											
14	Muscatine	45	35	20	85	5	10	80	15	10	0	80	20
15	Tonica	60	20	20	90	5	5	60	20	15	0	85	15
11	Elliott	Refer to data for Elliott in Group II soils											

[1] Percentages within a horizon occasionally total slightly more or less than 100 percent because evaluations were rounded to the nearest 5 percent.
[2] The D horizons of Muscatine (14) and Tonica (15) are calcareous glacial till as are the C horizons of Group II soils, and are especially similar to the C horizon of Elliott (11) which is of silty clay loam texture.
[3] Field notes indicate this horizon is loess.
[4] Only .5 percent of the total sample in this horizon is clay <.002 mm. in diameter.

Montmorillonite is the predominant clay mineral in the *C horizons* of all the loessial soils, Groups Iw and Ie (Table II). For both of these groups (Fig. 2) there is a tendency for the montmorillonite content to increase slightly with distance from what are usually considered the major loess sources, namely, the Mississippi river for Group Iw and the Illinois river for Group Ie. In group Iw the montmorillonite content varies from 80 percent in the C horizon of Joy (1) to 90 percent in the C horizon of Ipava (3). The C horizons of the loessial soils in Group Ie vary in montmorillonite content from 55 percent for Ipava (4) to 90 percent for Cisne (7).

The illite content in the C horizons of the loessial soils tends to decrease slightly with distance from the rivers (Fig. 2). For Group Iw the illite content in the C horizon decreases from 10 percent in Joy (1) to 5 percent in Ipava (3). The illite content in Group Ie decreases from 15 percent in the C horizon of Ipava (4) to 5 percent in Cisne (7).

The chlorite content of the C horizons of the loessial soils in Groups Iw and Ie varies from 5 to 30 percent but shows no consistent relation to distance from the rivers or the degree of weathering (Table II).

Montmorillonite is the predominant clay mineral in the *B horizons* for all of the loessial soils. Here again there is a tendency for the content of montmorillonite to increase slightly with distance from the rivers. In Group Iw the montmorillonite content in the B horizon of Joy (1) is 80 percent, with a slight increase to 90 percent in the same horizon for Ipava

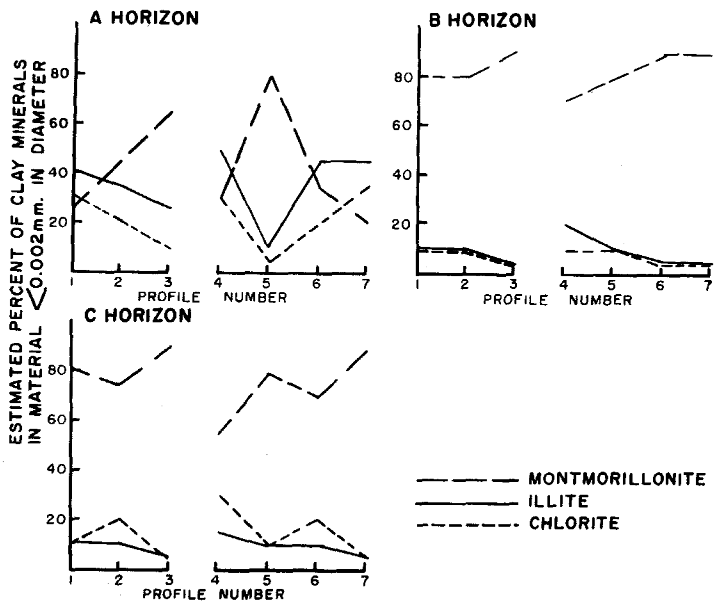

FIGURE 2.—Clay mineral composition of Group I soils developed from loess over Illinoian till.

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(3). In Group Ie the montmorillonite content in the B horizons increases from 70 percent in Ipava (4) to 90 percent in the B horizon of Cisne (7).

The illite content in the B horizons of Group I soils is low, varying from 5 to 20 percent. There is a tendency (Fig. 2) for the illite content to decrease slightly with distance from the Mississippi river for the Group Iw soils, and the Illinois river for the Group Ie soils.

The chlorite content of the B horizons for all of the loessial soils is rather low, ranging from 10 percent near the Mississippi river in Group Iw and the Illinois river in Group Ie, to 5 percent farther from the respective rivers.

The X-ray data are slightly less satisfactory for the *A horizons* than for the other horizons studied in that there was less uniformity in orientation from slide to slide. Furthermore, organic matter and the hydrogen peroxide treatment used to remove it from the A horizons may have interfered with complete fractionation and the recovery of proper amounts of fine clay material. Accordingly, some of the variation in the percentage of clay mineral types among samples from the A horizons may be due to reduced accuracy in analysis.

In Group I soils the average percent of montmorillonite decreases from 83 percent in the B horizons to 43 percent in the A horizons. The average illite contents are approximately 10 and 40 percent in the B and A horizons, respectively, and the chlorite contents in the same horizons are approximately 10 and 20 percent, respectively. Herrick (5) differs from the typical relationship outlined above in that the clay mineral composition of the A and B horizons are similar.

Eluviation of the finer montmorillonitic clay from the A into the B horizons as outlined by Bray (1935), concentrating the coarser illitic clay in the A horizons, can partly explain the relatively high percent of illite in the surface horizons. However, detailed comparison of the clay mineral composition in individual profiles of the loessial soils suggests that in many cases the difference in mineralogy between the B and C horizons is insufficient to account for the low montmorillonite content and build-up in the illite and chlorite content in the A horizons on the basis of differential eluviation. Additional work is in progress to investigate this problem.

Group II. — Most of the soils in Group II developed primarily from glacial till of Wisconsin age that includes a wide range in texture. The textural classes of the calcareous tills of the six profiles included in Group II are as follows: Warsaw (8), gravelly loam; Ringwood (9), sandy loam; Saybrook (10), loam; Elliott (11), silty clay loam; Swygert (12), silty clay; and Clarence (13), clay (Table I). The A horizons of all of the above soils are silt loams, suggesting the influence of loess or possibly silty, water-deposited material.

Illite is the predominant clay mineral in the *C horizon* for all the soils in Group II (Fig. 3), ranging from 60 to 80 percent, except in Warsaw (8) where 25 percent of the clay minerals is illite and 70 percent is montmorillonite (Table II). Field notes indicate that the solum of Warsaw, to a depth of 25 inches, developed from loess over calcareous, gravelly loam glacial till.

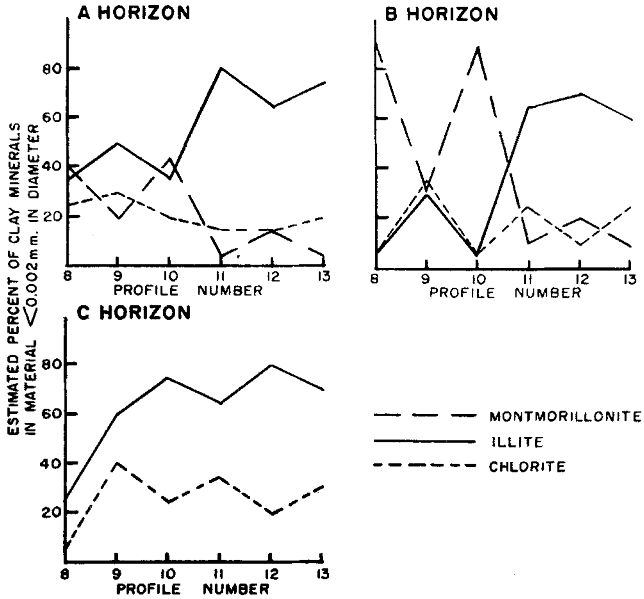

FIGURE 3. — Clay mineral composition of Group II soils developed primarily by Wisconsin till.

82.2 percent of this coarse-textured till is greater than 2 mm. in diameter and only 0.5 percent of it is clay less than 0.002 mm. in diameter (Table I). The predominantly montmorillonitic clay in the underlying, calcareous, coarse-textured glacial till of Warsaw could have been washed down from the silty A and B horizons above. Except in Warsaw (8), montmorillonite is absent in the underlying calcareous glacial tills of Group II soils, and the chlorite content varies from 20 to 40 percent. Warsaw (8) contains only 5 percent of chlorite.

Illite is the principal clay mineral, ranging from 60 to 70 percent, in the *B horizon* for three (profiles 11, 12, 13) of the six soils in Group II. The B horizon of Ringwood (9) contains approximately equal quantities of illite, montmorillonite, and chlorite. In the B horizon of Warsaw (8) and Saybrook (10) the illite content is only 5 percent, whereas the montmorillonite content is 90 percent. The sample studied in the B horizon of Warsaw (8) was taken at a depth of 19 to 25 inches, in what was described in the field notes as the lowest part of the loess in this profile. In Saybrook (10) the sample studied in the B horizon was taken from the 21- to 28-inch depth. Field notes for this profile state that the "material above 28 inches is probably mostly loess of Peorian age." Thus the high montmorillonite content of the clays from the B horizons of both Warsaw (8) and Saybrook (10) confirms field evidence that these horizons were developed from loess and not from till.

The montmorillonite content in the *A horizons* of Group II soils is low, varying from 5 to 20 percent, except in Warsaw (8) and Saybrook (10) where 40 and 45 percent, respectively, of the clay is montmorillonite. The A horizons, as well as the upper part of the B horizons, of the latter two soils are believed to be derived from loess. The low but significant amount of montmorillonite in the A and B horizons of the Group II soils, Ringwood (9), Elliott (11), Swygert (12), and Clarence (13), raises the question as to whether this montmorillonite developed as a result of weathering or again represents the influence of loessial material.

In this respect it is important to discuss in some detail the chlorite component of these till-derived soils, where the chlorite decreases in amount upward in the profile (Table II). There is also a qualitative change in the chlorite component which is of equal significance. Figure 6 shows spectrometer traces of each of the Elliott (11) samples before and after heating to 550° C for one-half hour. The chlorite of even the calcareous C horizon shows evidence of random interlayer hydration. This interlayer hydration becomes progressively more pronounced in the B and A horizons. In a sense, the chlorite component can be considered as a chlorite-montmorillonite mixed species, the "montmorillonite" phase becoming increasingly more prominent upward in the profile. That these phases are also sensitive to ethylene glycol treatment is confirmed by spectrometer data not included herein. It is necessary to conclude, therefore, that weathering is probably responsible for this variation in the character of the chlorite. One might conceivably project the process further and conclude that the montmorillonite (fully-expandable) phase occurring in small amounts in the A and B horizons of this soil was likewise derived by the weathering of chlorite. Consideration of the field relationships, however, which indicate a thin loess cover on this soil, suggests that the montmorillonite in the A horizon, and possibly in the B horizon, is due to both the influence of the loess cover and the weathering of chlorite and illite. The content of montmorillonite is 5 percent in the A horizon and 10 percent in the B horizon (Table II) of Elliott (11) and Clarence (13) where the loess is thinnest (Table I). Since this is the maximum amount that could be developed from illite and chlorite, any montmorillonite in excess of these amounts in other profiles studied is inherited from loessial parent material. If one did not consider field relationships adequately, it would be possible to interpret the differences in kinds of clay minerals as an example of a weathering sequence in each soil profile in Group II, rather than as being inherited largely from their parent material. That such conclusions are drawn, often incorrectly, is apparent from the literature.

Group III. — The soil profiles included in Group III were analyzed to obtain information concerning objective (d) of this study, and also to check the findings obtained for Groups I and II by studying Peorian loess and Wisconsin till where both materials occur in the same profile. The soils in Group III developed from thick to very thin loess over silty clay loam till of Wisconsin age (Table I).

Elliott (11) developed primarily from silty clay loam till and, therefore, was included as a member of the Group II soils. This profile is also included in Group III to represent a soil where the loess cover is very thin.

The underlying, calcareous, silty clay loam till in the *D horizon* of Muscatine (14) (Fig. 4) and Tonica (15) and the C horizon of Elliott (11) contains no montmorillonite (Table II). The illite content for these same horizons is 80, 85, and 65 percent, respectively, with chlorite being the other clay mineral present.

Total chemical analyses of the $<2\ \mu$ fraction of Muscatine (14) and Elliott (11) are shown in Table III. These data, particularly the K_2O content, confirm the X-ray analyses in pointing out the sharp break in mineral composition between the loessial A, B, and C horizons of Muscatine (14) and the silty clay loam till in the D horizon. The high K_2O content in the Elliott (11) confirms the predominance of illitic clay in this soil.

Resting on top of the silty clay loam till in Muscatine (14) and Tonica (15) is the calcareous loess or *C horizon* of these soils. X-ray studies indicate that the clay mineral composition of this loess (Fig. 5) is like that of other loess in Group I soils, and that it is very different from the underlying, calcareous, silty clay loam till (Fig. 5, D horizon) which has the characteristic clay mineral composition of the tills in Group II soils. The clay fraction of the calcareous loess or C horizon in Muscatine (14) and Tonica (15) is composed of 80 and 60 percent, respectively, of montmoril-

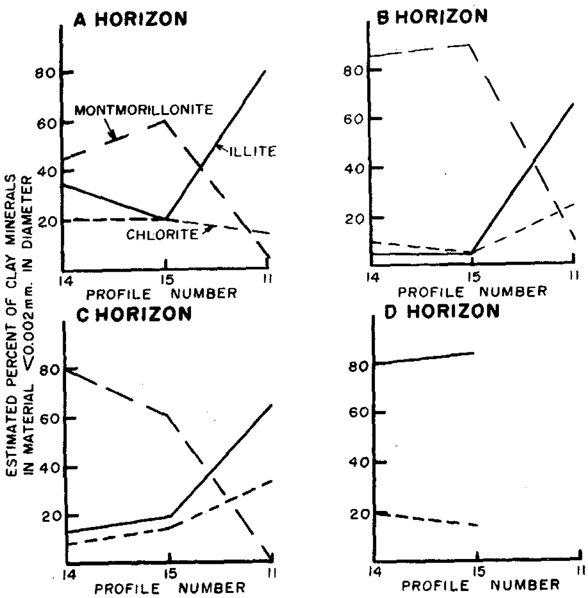

FIGURE 4. — Clay mineral composition of Group III soils developed from thick to thin loess on Wisconsin till.

TABLE III. — CHEMICAL COMPOSITION[1] OF THE <2 μ FRACTION OF MUSCATINE (14) AND ELLIOTT (11) SOILS

Profile No.	Soil series	Horizon	Sample number	SiO_2 pct.	Al_2O_3 pct.	Fe_2O_3 pct.	TiO_2 pct.	MgO pct.	CaO pct.	K_2O pct.	Na_2O pct.	Loss on ignition pct.
14	Muscatine	A	17806	53.47	21.28	9.07	0.83	2.15	0.57	2.52	0.85	9.99
		B	17809	50.94	21.04	10.07	0.67	2.37	1.07	1.64	0.72	11.78
		C	17812	50.53	19.12	11.88	0.70	2.89	1.69	2.67	0.89	9.97
		D	17814	47.73	19.70	7.95	0.88	3.92	3.85	5.28	0.93	10.16
11	Elliott	A	17504	53.01	22.24	7.76	0.90	2.38	1.10	4.05	0.42	8.28
		B	17508	50.94	21.86	8.81	0.81	3.21	0.91	4.46	0.76	8.51
		C	17511	46.84	19.81	7.81	0.67	4.26	5.34	4.67	0.55	10.45

[1] The authors are grateful to the Illinois State Geological Survey for making these analyses.

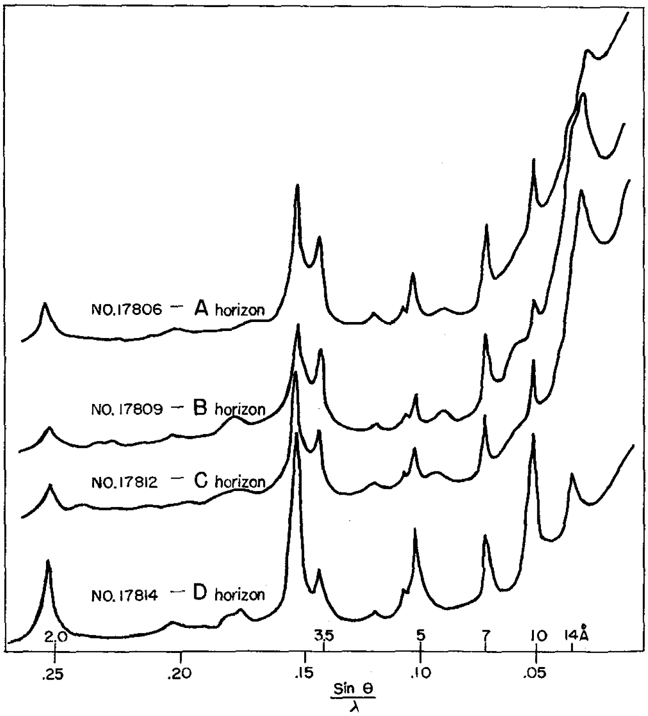

FIGURE 5. — Smooth spectrometer traces of the ethylene glycol-treated $< 2\ \mu$ clay fraction of Muscatine (14) showing in particular the marked contrast between the calcareous C and D horizons.

lonite together with some illite and chlorite. In the C horizon of Tonica (15) the thin layer of calcareous loess contains less montmorillonite but more illite than most other calcareous loesses, possibly because it was mixed to some extent with the underlying glacial till. As is indicated above, the C horizon of Elliott (11) exhibits the typical X-ray pattern of glacial till, having 65 percent illite and 35 percent chlorite, but no montmorillonite.

For the *B horizon* of Muscatine (14) (Fig. 4) and Tonica (15) the montmorillonite, illite, and chlorite contents average 88, 5, and 8 percent, respectively. The high montmorillonite content indicates that loess is the parent material for these two soils. The B horizon of Elliott (11) contains only 10 percent of montmorillonite. The illite content is 65 percent and the chlorite content is 25 percent. The small percentage of montmorillonite suggests that the silty clay loam till is the parent material from which this horizon developed, with only a minor amount of montmorillonite clay coming from the overlying loess.

The *A horizons* of Muscatine (14) (Fig. 4) and Tonica (15) contain an average of 53 percent montmorillonite, 28 percent illite, and 20 percent chlorite. The above averages are similar to the average content of these clay minerals in the loessial soils in Group I.

In the A horizon, Elliott (11) contains 5 percent montmorillonite, 80 percent illite, and 15 percent chlorite. There is a strong suggestion from the above data that loess, containing montmorillonitic clay, has influenced the development of profile 11 to only a minor extent.

SUMMARY AND CONCLUSIONS

Montmorillonite is the principal clay mineral in all of the loessial soils included in this study. X-ray patterns indicate that the crystal structure of montmorillonite in the Peorian loess in Illinois has not been materially altered by soil weathering and developmental processes. In spite of evidence of significant weathering as reflected by regular variation in loess depth, carbonate content, particle size, base saturation, pH, etc. (Table I), there is a remarkable uniformity in the kinds of clay minerals in the loess soils of Groups Iw and Ie. The preponderance of montmorillonite throughout, even in calcareous horizons, indicates that this mineral is stable under conditions prevailing during and since loess deposition.

Illite and, to a lesser extent, chlorite are the principal clay minerals in the calcareous glacial tills of Wisconsin age. In the soils that developed primarily from till, there is a suggestion, from the data of this study, that some montmorillonite may have formed as an alteration product of chlorite and illite, or possibly formed from primary minerals of silt size.

In those soils where the sola developed from both loess and till of Wisconsin age, the type and amount of clay minerals tend to differ with differing parent material. Illite and chlorite are the two principal clay minerals in the C horizon or till of Group II soils, and montmorillonite is the principal clay mineral in the upper horizons where loess is present. Saybrook (10) is an example of such a soil developed from loess over calcareous loam till of Wisconsin age. An isolated study of the clay minerals in a soil of this origin could easily lead to an erroneous conclusion, namely that the montmorillonite in the upper horizons is the weathered product of illite and chlorite. In soil profiles (14, 15) where calcareous Peorian loess rests on calcareous till of Wisconsin age, the data clearly show that the dominant clay mineral in the loess is montmorillonite, and the principal clay minerals in the glacial till are illite and chlorite. Even in those cases (soil profiles 9, 11, 12, 13) where glacial till has contributed most significantly to soil development, minor amounts of montmorillonite in the surface horizons can logically be attributed to loessial influence as well as degradation of till-derived clays. That both factors are influential in these cases is most likely.

Thus, evidence indicates that variations in the *kind* of clay minerals in the soils of Illinois are primarily the result of different parent materials and, to a much lesser extent, are the result of weathering processes. Weathering, of course, markedly increases the *amount* of clay in Illinois

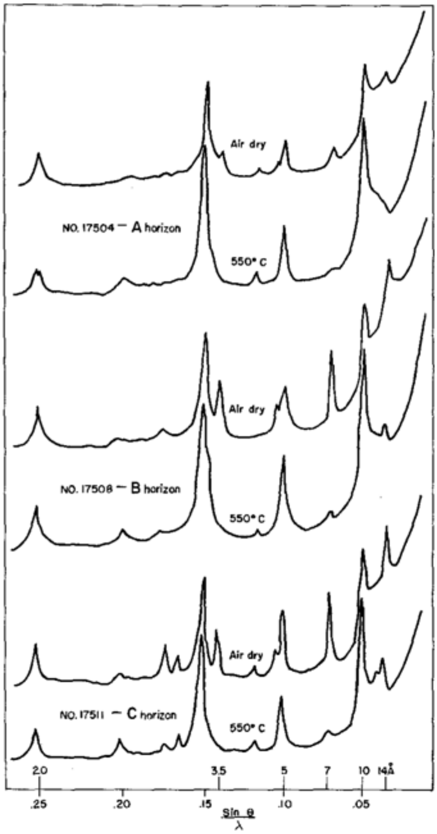

FIGURE 6. — Smooth spectrometer traces of the < 2 μ fraction of Elliott (11) in the air-dry state and following ignition to 550° C, showing in particular the upward decrease in amount and quality of the chlorite component.

soils, and in certain instances tends to change the proportions of the various kinds of clay minerals.

One of the most striking results of this study is the marked difference found in the kind of clay minerals in the loess in comparison with glacial till of Wisconsin age. This is even more remarkable in light of the currently accepted hypothesis that Peorian loess in Illinois emanated from the flood plains of the major nearby rivers that carried melt waters and sediments from the glacial tills of Wisconsin age in northeastern Illinois. The preponderance of montmorillonite and the small amounts of illite and chlorite, especially in unweathered calcareous loess, suggest that there is very little genetic relationship between the clay mineral components of loess and till. It is very unlikely that, under such conditions as existed, montmorillonite could have been formed during transport or during loess deposition from illitic glacial clays. It is necessary to conclude that most of the clay mineral fraction of the loessial materials studied did not emanate from the flood plains of rivers choked with glacial debris from northeastern Illinois, even though the distribution pattern of Peorian loess suggests that the silt fraction came from this source. From the identity of clay minerals in loess from Kansas (Swineford and Frye, 1951), it seems likely that in Illinois also the clay material was derived largely from a western source, namely, the montmorillonitic and bentonitic soils and sediments of the Great Plains region. In order to fully evaluate some of these suggestions, it is apparent that it will require the combined efforts of soil scientists, geologists, and mineralogists over a wide area.

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