WEATHERING IN A SANGAMON PALEOSOL[1]

A. H. BEAVERS AND ROBERT L. JONES

Department of Agronomy, University of Illinois, Urbana, Illinois

ABSTRACT

Aspects of weathering in loam-textured Illinoian till and overlying loess were studied. Silt-size iron, calcium, and potassium minerals weathered in the B2 and B3 horizons in amounts similar to those in fairly youthful modern Gray-Brown Podzolic soils developed in loess along the Mississippi River. In the clay fraction, weathering procedes from illite through expandable vermiculite to chloritic vermiculite. Kaolinite occurs in increasing amounts toward the surface of the buried soil. Despite its age and physical appearance, this soil is not judged to be in an advanced stage of weathering.

INTRODUCTION

Great emphasis is placed on the physical appearance of paleosols in the field. For example, red hues and occurrence of "resistant" pebbles give the paleosol attributes of great age or prolonged extent of weathering. It is not uncommon to find in the literature or to hear at the outcrop that a certain parent material must be of this or that age because of paleosol texture, consistency, and/or occurrence of resistant rock types, and rather extensive correlations are made on the basis of these readily discernable attributes. For example, acquaintance with modern soils leads us to infer that high clay accumulation is related to advanced development; red hues require good internal drainage and some authors even conjure up warm climates to explain them. Such correlations and inferences concerning correlation, mode of soil development, and concomitant climatic and floristic conditions are desirable and, indeed, are a part of the science. Unfortunately, our knowledge of the extent and nature of weathering of many paleosols is neither characterized nor known in a quantitative manner.

We have applied several current soil mineralogical investigative techniques to study of the Sangamon soil developed in Illinoian till occurring in the Reliance Whiting Quarry, Alton, Illinois. The section from which this paleosol was collected was viewed at stop 3 on the 14th Annual Meeting of the Midwestern Section of the Friends of the Pleistocene. A detailed description of the section is given in the guidebook to that meeting (Frye and Willman, 1963).

Paleosol Description

Paleosol developed in Illinoian till (NW¼, SE¼, NE¼, sec. 11, T5N, R10W, Madison Co., Illinois). Descriptions on a dry sample basis. The pH values are for a 1:1 soil-water paste.

Horizon	Depth (in.)	Description
A	0–12	Brown (7.5YR 5/4) very hard silt loam; medium to coarse subangular blocky structure; pH, 7.5. Diffuse boundary. Probably mixed till and Loveland (?) Loess.
B1	12–24	Strong brown (7.5YR 5/6) very hard silt loam; medium to coarse subangular blocky structure; pH, 7.4. Diffuse boundary. Probably mixed till and Loveland (?) loess.
II B2	24–38	Brown (7.5YR 5/4) hard loam; fine to medium strong subangular blocky structure breaking to fine subangular blocky structure; pH, 7.2; continuous thin clay coatings; many small angular white chert fragments. Diffuse boundary.

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II B3	38–50	Yellow (10YR 7.5/6) breaking to reddish brown (5YR 4/4) (ped interiors) hard loam; medium to coarse subangular blocky structure; pH, 7.3; continuous thin clay coatings; many small angular white chert fragments. Diffuse boundary.
II C	50+	Very pale brown (10YR 7/4) hard loam till; massive to weak very coarse subangular blocky structure; pH, 8.1; calcareous.

About 10 ft of Peoria Loess, 14 ft of Roxana Loess, and 2 ft of Loveland Silt overlie the paleosol. The paleosol represents weathering during Sangamon time. Truncation by erosion of till soil and mixing with overlying loess are probable. The identification of the Loveland Silt mixed in the surficial horizons is by Frye and Willman (1963).

METHODS

Mechanical analyses were carried out by pipette and wet-sieve methods. Elemental determinations were made by x-ray spectrographic analysis using sample preparation methods described by Beavers (1960), except for silica which was determined from samples prepared according to the fusion method of Rose et al. (1963). National Bureau of Standards samples approaching the matrix characteristics of the soil samples were used as standards. Extractable iron was determined using the dithionite method of Mehra and Jackson (1960). Magnetic susceptibility was determined with a Faraday balance using mercury tetrathiocyanatocobaltate (16.4 x 10^{-6}cgs) as a reference standard. X-ray diffractometer patterns were obtained from parallel-oriented clays saturated with sodium and potassium. In addition, potassium-saturated samples were heated at 550 C for 30 min. Differential thermal analyses were performed on potassium-saturated A- and C-horizon clays using 12-mg sample and 20 C/min heating rate (DuPont 900 Thermoanalyzer). Carbonate content was determined from gas gravimetric determination of acid-treated samples.

RESULTS AND DISCUSSION

The horizons defined in the field separate naturally into a vertical sequence suggesting clay accumulation in the B2 horizon (table 1). Silt contents in the A and B1 horizons indicate mixing of loess with the loam-textured till.

TABLE 1
Mechanical analysis data

Hor.	Sand (mm) 1–2 %	0.5–1 %	0.25–0.5 %	0.1–0.25 %	0.05–0.1 %	Total %	Silt (μ) 20–50 %	2–20 %	Clay (μ) <2 %
A	1.3	3.6	8.0	11.2	9.0	33.0	30.4	24.7	11.9
B1	2.0	4.2	9.3	13.0	9.0	37.4	25.1	23.2	14.2
B2	3.5	4.8	10.3	14.8	8.3	41.7	16.2	18.1	24.1
B3	2.5	6.6	12.4	17.1	7.5	46.1	13.7	20.5	19.7
C	3.4	6.2	9.8	14.6	7.0	41.0	19.1	26.7	13.2

Alkaline pH of the A and B horizons of the paleosol is taken to reflect calcium and magnesium saturation of the colloidal fraction by movement of ground waters from overlying Peorian loess, which is calcareous in part.

The elemental analyses (table 2) indicate the extent of weathering in the fine-silt (2 to 20 μ), coarse-silt (20 to 50 μ), and sand (>50 μ) fractions. Converting the elemental data to molar ratios using zirconium as a basis (table 3) gives an indication of the extent of weathering. Disregarding the A and B1 horizons, which field observation and analytical data indicate are developed in an admixture of loess and till, the ratios indicate that there has been marked weathering of calcium- and iron-bearing minerals in all fractions except the sand, where the occurrence of iron concretions makes meaningful interpretations of iron transformation difficult or impossible. Potassium-bearing minerals have weathered in the silt fractions, but appear to be concentrated in the sand-size fraction. When ratios are compared with the C horizon, there appear to be similar amounts of cal-

TABLE 2

Partial chemical analysis of fine-silt (2 to 20 μ), coarse-silt (20 to 50 μ) and sand fractions (>50 μ) and magnetic susceptibility and carbonate equivalent

Horizon	K_2O 2–20 μ %	K_2O 20–50 μ %	K_2O >50 μ %	CaO 2–20 μ %	CaO 20–50 μ %	CaO >50 μ %	Fe_2O_3 2–20 μ %	Fe_2O_3 20–50 μ %	Fe_2O_3 >50 μ %	ZrO_2 2–20 μ %	ZrO_2 20–50 μ %	ZrO_2 >50 μ %	SiO_2 2–20 %	SiO_2 20–50 %	Mag. Sus. X10^{-6} cgs.	$CaCO_3$ equiv. %
A	2.49	2.06	1.73	0.68	0.84	0.36	1.90	1.01	0.59	0.037	0.078	0.015	82.68	91.15	14.5	
B1	2.53	1.99	1.67	0.53	0.68	0.30	2.06	0.87	0.57	0.036	0.078	0.018	86.56	88.86	13.4	
B2	2.67	1.89	1.61	0.30	0.37	0.27	2.13	0.78	0.81	0.038	0.087	0.015	90.17	95.36	8.8	
B3	2.93	2.09	1.61	0.33	0.43	0.37	2.71	1.07	0.80	0.033	0.073	0.015	89.67	95.69	7.4	
C	2.62	1.84	1.52	0.53	0.74	0.65	2.92	1.39	1.11	0.029	0.061	0.020			3.6	13.24

cium and iron removed from both the B2 and B3 horizons. Evidently, potassium is present in more resistant minerals because proportionately less has been removed from the B2 and B3 horizons. It is particularly noteworthy that potassium appears concentrated in the sand fractions of the B2 and B3 horizons, as indicated by high K_2O–ZrO_2 ratios. This concentration is due in part to loss of carbonate minerals in the C horizon. The general sequence of weathering giving a weathering potential scheme of $Fe \geq Ca > K$ is similar to that cited by Jones and Beavers (1964) for deep loess soils in west-central Illinois. Summation of the elemental analyses for the coarse-silt fraction indicates almost total analysis for the B2 and B3 horizons. These samples lost less than 1 per cent by weight as volatile matter during fusion preparatory to x-ray spectrographic analysis, indicating a minimum of hydroxilated minerals.

TABLE 3

Molar oxide weathering ratios

Horizon	CaO/ZrO_2 2–20 μ	CaO/ZrO_2 20–50 μ	CaO/ZrO_2 >50 μ	Fe_2O_3/ZrO_2 2–20 μ	Fe_2O_3/ZrO_2 20–50 μ	Fe_2O_3/ZrO_2 >50 μ	K_2O/ZrO_2 2–20 μ	K_2O/ZrO_2 20–50 μ	K_2O/ZrO_2 >50 μ
A	40.3	21.7	53.3	39.3	9.1	30.8	86.7	31.7	153.3
B1	32.4	17.5	35.3	44.5	7.8	24.0	93.1	30.6	118.0
B2	17.1	9.3	40.0	42.9	6.8	42.5	90.3	28.3	142.5
B3	21.8	13.0	55.0	63.0	11.4	42.5	115.1	37.6	142.5
C	39.2	26.4	72.5	76.2	17.4	43.8	115.8	39.0	100.6

Unfortunately, data for weathering of loam-textured Wisconsin-age till are not available, therefore specific comparisons for weathering during recent time are not possible. However, an idea of the extent of weathering in the Sangamon profile can be obtained by comparison with weathering in the thin-loess soils of southern Illinois (table 4). Beavers et al. (1963) reported data for fragipan soils (cf. Hosmer) that show differences in CaO–ZrO_2 ratios from those found in the Sangamon soils. Effective weathering time of the loess, in which the fragipan soils are developed, probably approaches 20,000 years. There are great differences in weathering between the B2 and B3 horizons of the fragipan soils, which is a reflection of their unique development. Comparisons, therefore, between the fragipan soils and Sangamon soil are not justifiable, but the data for these soils do provide an idea of the extent of weathering possible. However, the similarity in magnitude of weathering in the B2 and B3 horizons of the Alford soil, as compared to the Sangamon soil, is remarkable and, considering the fact that these soils are similar in internal drainage characteristics, one must conclude that the Sangamon profile is not in an advanced stage of weathering. In the relatively youthful deep-loess soils of western Illinois (Jones and Beavers, 1964), which have undergone weathering for at least 10,000 years and probably 15,000 years, CaO–ZrO_2 ratios are much higher, but also exhibit the same order of magnitude of increase with depth that the Alford and Sangamon soils possess.

Molar ratios computed for the total-silt fraction of Pana and Hickory soils developed in loam- and gravelly loam-textured Illinoian till are similar to the ratios in the Sangamon soil. The B and C horizons of the Hickory profile are

TABLE 4

Comparison of CaO–ZrO_2 ratio of Sangamon profile weathering with modern soils in southern Illinois[1]

Hor.	Sangamon		Alford		Hosmer		Ava		Grantsburg		Pana	Hickory
	2–20 μ	20–50 μ	2–20 μ	20–50 μ	2–20 μ	20–50 μ	2–20 μ	20–50 μ	2–20 μ	20–50 μ	2–50 μ	20–50 μ
A	40.3	21.7	18.6	7.4	15.1	6.5	9.8	4.4	9.2	4.3	—	—
B1	32.4	17.5	18.1	8.0	—	—	9.9	4.3	—	—	—	—
B2	17.1	9.3	19.9	9.9	14.6	6.3	12.5	6.6	11.0	5.1	19.3	9.2
B3	21.8	13.0	23.5	11.9	33.4[2]	12.3[2]	26.4[2]	13.4[2]	24.4[2]	12.2[2]	17.4	14.2
C	39.2	26.4	25.0	13.9	8.9[3]	3.7[3]	—	—	—	—	24.7	52.4

[1]Alford is a Gray-Brown Podzolic soil developed in thick loess. Hosmer, Ava, and Grantsburg are fragipan soils developed in thin loess. Pana and Hickory are Brunizem and Gray-Brown Podzolic soils, respectively, developed in loam-textured Illinoian till (data from Hall, unpub. M.Sc. Thesis, Univ. of Ill., 1961).

[2]Horizon occurring in lower sequum of bisequal profile.

[3]Illinoian till, Hosmer sample from A horizon of paleosol.

similar in color and texture to the Sangamon soil. Surprisingly, the Pana and Hickory soils do not show greater weathering because they have been subjected to a long weathering interval represented by Sangamon, Wisconsin and Recent time. The thin Wisconsin-age (from 15 to 39 inches on Pana and 17 inches on Hickory) loess caps are probably insignificant influences in the weathering of these soils when weathering of the post-Illinoian interval is compared.

The Sangamon and Hickory soils are similar in extent of weathering. This weathering is not as great as we might have judged, in that calcium- and iron-bearing minerals have weathered, but the soils are far from senile or being spent in weatherable minerals. Good internal drainage has undoubtedly been of primary importance in the development of these two soils, the sola of which contrast markedly with the poorly drained gumbotil and accretion-gley profiles common to the buried Illinoian topography in southern Illinois.

Total iron and extractable iron contents (table 5) indicate that the B2 and B3 have similar amounts of total iron; however, weathering has produced more extractable iron (presumably hematitic) in the B2 horizon. Some iron has eluviated into these horizons, but if iron in the C horizon is calculated on a carbonate-mineral-free basis, the data indicate little translocation, although primary iron-mineral transformation has been significant.

Magnetic susceptibility data (table 2) indicate clearly that the A and B1 horizons are different material. Decrease in susceptibility in the C horizon, with values below those of the B2 and B3 horizons, is interpreted to be a result of dilution of magnetic components in the C horizon by carbonates and also to paramagnetic secondary iron oxides, which contribute to higher susceptibility in the B horizons.

The carbonate present in the C horizon is dolomite. Using the CO_2 absorption data, there is 12.18 per cent dolomite (assuming an ideal 1:1 mineral) in the C horizon. Absence of accessory calcite probably indicates some leaching of the more acid labile calcite. The amount of carbonate is lower than the average of 28.9 per cent calcium carbonate equivalent reported by Wascher et al. (1960) for loam-textured Wisconsin-age tills in northeast Illinois.

TABLE 5

Total and extractable iron and percent of iron extractable

Horizon	Total Fe_2O_3 %	Ext. Fe_2O_3 %	% Ext.
A	3.63	2.18	60.0
B1	3.74	2.04	54.5
B2	5.09	3.73	73.3
B3	5.14	3.31	64.4
C	4.35	2.92	67.1

Clay mineral differentiation among the horizons of the Sangamon soil are best followed by reference to kaolinite and expandable mineral reflections (fig. 1). Expandable minerals interlayered with micaceous (10A) components are most prominent in the A horizon and less so in the B1 horizon although they aggregate less than the amount of illite. With sodium saturation, these minerals give a broad slope from the high angle side of 10A and, upon potassium saturation, highly surface-charged expandable minerals collapse, giving a high, broad peak extending from 14A into the region of scatter from the primary x-ray beam. Using a ratio of 7A to 10A net intensity ratios, the diffractogram data can be reduced to show a persistent decrease of 7A material (both kaolinite and second-order chloritic vermiculite) with depth. For horizons A, B1, B2, B3, and C, the ratios of potassium-saturated samples are 0.64, 0.45 0.47, 0.28, and 0.32, respectively. From differential thermal analysis, the difference in the area of the endotherm representing loss of hydroxyls in kaolinite is 3.8 times greater in the A horizon than in the C horizon, indicating that much of 7A decrease in intensity is due to kaolinite content differences. The ratio of kaolinite to illite is similar in the B1 and B2 horizons. The B3 and C horizons are similar in kaolinite-illite ratios and in the occurrence of expandable minerals.

Because of mixing in the A and B1 horizons, it is difficult to establish a weathering scheme for clay minerals in this soil. In the A2, B1, and B2 horizons, there is a mixed-layer assemblage of 14A and expandable species; the prominence of 14A species is markedly decreased in the B2 horizon (fig. 1). The 14A component is probably chloritic vermiculite and represents the accumulation of aluminium polymers in interplanar positions made available by loss of potassium through weathering. Collapse to 10A upon potassium saturation is not possible at the state of weathering of these soils due to the interpolation of the polymers; however, the organization of the polymers has not become such that the weathered platelets will not swell on sodium saturation and glycolation, which is indicative of the formation of "soil chlorite" (Jackson, 1963). The diffuse reflection extending from 11A into the 20A region in the B3 and C samples suggests early stages of mica weathering and formation of the interlayer minerals that are more abundant in the B2 and higher horizons. The heated patterns indicate that the interlayer material does not make up a substantial portion of the total clay mineral assemblage. Almost no "shoulder" occurs on the low angle side of the 10A reflection in the C horizon.

In summary, the clay mineral fraction is characterized by an abundance of illite throughout. Kaolinite, some of which may be syngenetic with overlying loess and consequently mixed with the till, occurs in decreasing amount with

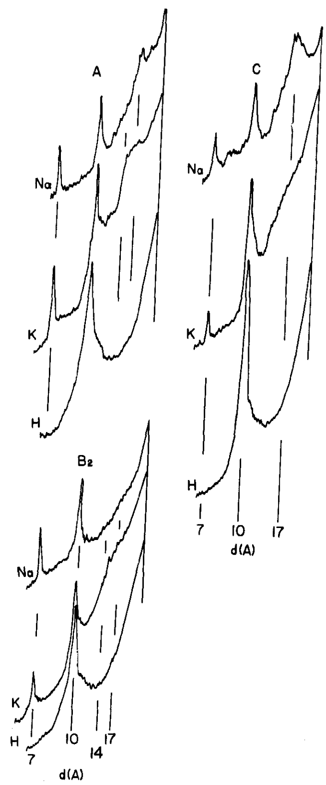

FIGURE 1. X-ray diffractograms for clay fraction of A, B2, and C horizons. Na, K, and H refer to sodium-saturated, potassium-saturated, and heated samples respectively. Sodium and potassium samples in glycolated condition. Recording is linear.

depth. An interlayer assemblage, comprised of what is thought to be chloritic vermiculite and montmorillonite-type minerals, is most abundant in surficial horizons. The interlayer assemblage is authigenic, although there is a minor amount of interlayer material inherited from the parent till. A tentative weathering scheme suggested for the clay minerals if (cf. Jackson, 1962) illite→ expandable vermiculite→ montmorillonite-chloritic vermiculite interlayer assemblage→ minor kaolinite. This is essentially the scheme suggested by Jones and Beavers (1964) for youthful loess-derived soils in western Illinois.

CONCLUSION

There is evidence of truncation of surficial horizons of this Sangamon soil in addition to mixing with overlying loess thought to be equivalent to Loveland

Loess. Weathering of the B2, B3, and C horizons resembles that in a Hickory soil which is also derived from coarse-textured Illinoian till and also loessial Seaton, Fayette, and Clinton soils in western Illinois. Although there has been marked weathering of silicate minerals, including calcium- and iron-bearing minerals and potassium minerals to be lesser degree, the extent or intensity of weathering does not approach that observed in the B horizons of fragipan soils developed in thin Peoria Loess in southern Illinois. Clay-mineral alteration is characterized by formation of a 14A interlayer assemblage and expandable types, the precursor of which is illite. In this respect, the paleosol also resembles youthful soils of western Illinois. Because of the alkaline pH and influence of overlying loess, weathering associated with hydronium ion has been surpressed since the paleosol was buried — most recently by Peoria Loess. Other paleosols, more complete in amount of solum preserved, are under study, and it is hoped that eventually this Sangamon soil can be placed in a more conclusive frame of reference.

LITERATURE CITED

Beavers, A. H. 1960. Use of x-ray spectrographic analysis for the study of soil genesis. Trans. 7th Int. Cong. of Soil Sci. 2: 1–9.

Beavers, A. H., J. B. Fehrenbacher, P. R. Johnson and **R. L. Jones.** 1963. $CaO\text{-}ZrO_2$ molar ratios as an index of weathering. Soil Sci. Soc. Am. Proc. 27(4): 408–412.

Frye, J. C. and **H. B. Willman.** 1960. Classification of the Wisconsinan stage in the Lake Michigan glacial lobe. Ill. State Geol. Surv. Cir. 285. 16 p.

——— and ———. 1963. Loess stratigraphy, Wisconsinan classification and accretion-gleys in central-western Illinois. Guidebook 14th Ann. Meet. Midwest Sect. Friends of the Pleist. 37 p.

Jackson, M. L. 1958. Soil chemical analysis. Prentice Hall, Englewood Cliffs, N. J. 498 p.

———. 1962. Interlayering of expansible layer silicates in soils by chemical weathering. Clays and Clay Min., Proc. 11 Nat. Conf. on Clays and Clay Min. p. 29–46.

Jones, R. L. and **A. H. Beavers.** 1964. Some mineralogical characteristics of Seaton, Fayette, and Clinton soils in Illinois. Bull. Ill. Agr. Exp. Sta. (in press).

Mehra, O. P. and **M. L. Jackson.** 1960. Iron oxide removal from soils and clays by a dithionite citrate system buffered with sodium bicarbonate. Clays and Clay Min., Proc. 7 Nat. Conf. on Clays and Clay Min. p. 317–327.

Rose, H. J., Jr., I. Adler and **F. J. Flanagan.** 1963. X-ray fluorescence analysis of the light elements in rocks and minerals. App. Spect. 17(4): 81–85.

Wascher, H. L., J. D. Alexander, B. W. Ray, A. H. Beavers, and **R. T. Odell.** 1960. Characteristics of soils associated with glacial tills in northeastern Illinois. Ill. Agr. Exp. Sta. Bull. 665, 155 p.