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Cation Exchange Capacity of the Clay Fraction of Loess in Southwestern Iowa

By D. T. DAVIDSON AND J. B. SHEELER

The cation exchange capacity of clay-size material extracted from soil with a low organic matter content is largely dependent on the kinds of clay minerals present. If the extracted clay is composed mostly of one kind of clay mineral, the exchange capacity will indicate what that mineral is. This paper reports on cation exchange capacity determinations made on the minus 2 micron clay-size range of selected samples of loess from the southwestern Iowa area shown in Figure 1.

WHOLE LOESS SAMPLES

The origin, distribution, and property variations of the Wisconsin

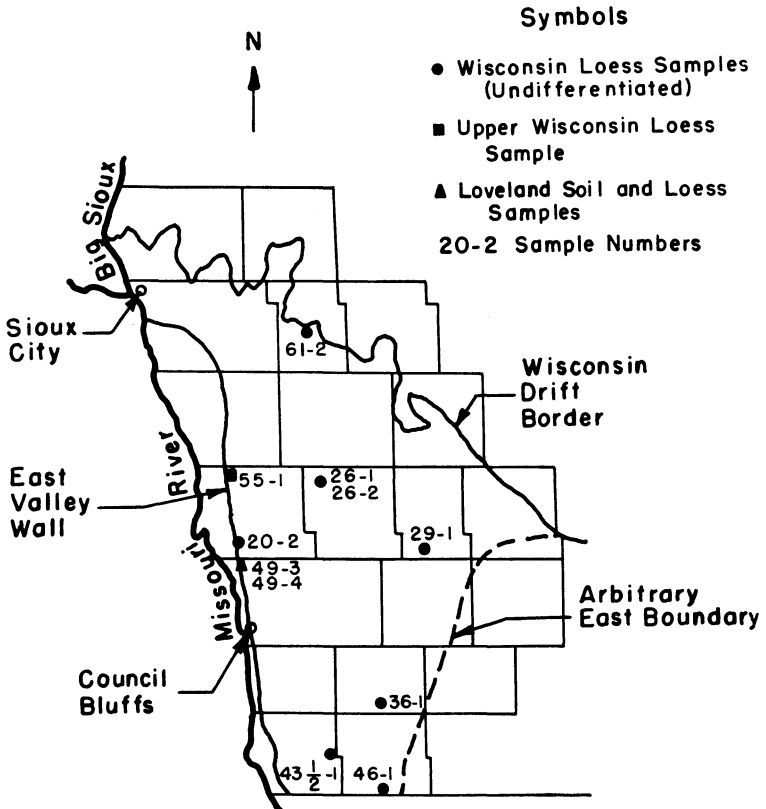


Figure 1. Distribution of sampling locations in southwestern Iowa loess area. Symbols indicate age classification of loess sampled.

sin* loess which mantles much of the southwestern Iowa area shown in Figure 1 have been discussed in previous papers (1, 2, 3). The minus 2 micron clay fractions used in the study reported in this paper were extracted from eleven samples of whole loess which were selected as representing the range in properties of the more than 150 loess samples that have been tested in the property variation studies of the Iowa Engineering Experiment Station.

Descriptive information of the locations from which the whole loess samples were taken are given in Table I, and the distribution of sampling locations is shown in Figure 1. Sample 55-1 is Upper Wisconsin or Cary-Mankato loess from the Pisgah road section identified by Ruhe (4). The other Wisconsin age loess samples are undifferentiated because the buried (Brady) soil (6) which separates the upper and lower Wisconsin components was not present. The samples of Loveland soil† and of Loveland loess from the type section at Loveland, Pottawattamie County, were included in the study for comparative purposes.

Table II gives some properties of the whole loess which are indicative of the cation exchange material in the samples. The Wisconsin loess samples are arranged in this table in the order of increasing clay content. The range in clay content of the Wisconsin loess in southwestern Iowa is shown by these samples. Whether the type section Loveland samples used herein are representative of Loveland soil and loess exposed elsewhere in southwestern Iowa is not as yet known. The Loveland soil had a higher clay content than the underlying loess, and both Loveland samples had lower clay contents than some of the more plastic Wisconsin loess samples.

Sample 26-2 is from the same location as sample 26-1 but was taken at a greater depth in the Wisconsin loess section. Both samples contain practically the same amount of clay. However sample 26-2 is unoxidized and unleached, and sample 26-1 is oxidized and leached. Sample 26-2 was included in the study to determine what effect oxidation and leaching might have on the clay mineral present in the loess. This was the only unoxidized sample used in the study.

The organic matter content of all samples was low, and for this reason the inorganic clay minerals are considered to be largely responsible for cation exchange. Carbonate contents were variable, being relatively high for unleached samples taken near the major source areas of the loess (3). The distribution of carbonates in

*Also referred to as Peorian loess in the geological literature.

†Sangamon soil profile on Loveland loess.

Table 1
Loess Sampling Locations in Southwestern Iowa.

Sample No.	Material	Age classification	Sampling depth ^c (ft.)	Location		
				County	Section	Township North Range West Soil series
55-1	Loess	Upper Wisconsin ^b	2½—3½	Harrison	SW/c,S-8	81 44 Hamburg
20-2	"	Wisconsin (Undifferentiated)	39—40	Harrison	S-15 ^f	78 43 Hamburg
61-2	"	"	17—18	Ida	NW¼,S-9	87 40 Monona
26-1	"	"	4—5	Shelby	SE¼,S-21	81 40 Monona
26-2	"	"	10—11	"	"	" " "
29-1	"	"	5—6	Audubon	NW/c,SW¼,S-13	78 36 Marshall
36-1	"	"	5½—6½	Montgomery	SE¼,NE¼,S-14	72 38 Marshall
43½-1	"	"	5—6	Fremont	NW/c,S-36	68 40 Marshall
46-1	"	"	5—6	Page	NW¼,S-30	67 37 Marshall
49-3	Soil ^a	Loveland	55 ^d	Pottawattamie	SE/c,NW¼,S-3 ^e	77 44 Hamburg
49-4	Loess	"	65 ^e	"	"	" " "

^aSangamon soil profile on Loveland Loess.

^bAlso called Cary-Mankato loess and Bignell loess. Sampled from Pisgah road section (4).

^cMeasurements are from earth's surface.

^dSampled from about middle of 10 ± ft. Sangamon soil profile.

^eSampled in Loveland loess about 3 ft. above slump.

^fSampled from bluff behind third ward school in city of Missouri Valley.

^gSampled from type section of Loveland loess at northeast edge of town of Loveland (5).

Table 2
Some Properties of Whole Loess Samples.

No.	Sample Age Classification	Textural Composition ^a				Organic matter (%)	Carbonates (%CaCO ₃)	Oxidation	pH	Cat. Ex. Cap (m.e./100g)	Plas- ticity Index (%)	B.P.R. ^b Classifi- cation
		Sand (%)	Silt (%)	Clay (%)								
				-5μ	-2μ							
55-1	Upper Wisconsin Wisconsin	4.0	82.6	13.4	12.0	0.24	11.0	Oxidized	8.4	11.2	2.3	A-4(8)
20-2	(Undifferentiated)	1.4	78.8	19.8	16.0	0.17	10.2	Oxidized	8.7	13.4	6.2	A-4(8)
61-2	"	5.2	70.8	24.0	19.8	0.15	11.5	Oxidized	8.3	14.2	10.8	A-6(8)
26-1	"	2.0	70.6	27.4	22.4	0.18	1.4	Oxidized	7.0	18.2	12.5	A-6(9)
26-2	"	0.9	69.8	29.3	23.1	0.17	8.7	Unoxidized	8.3	17.9	17.8	A-6(9)
29-1	"	1.0	67.9	31.1	25.0	0.25	2.9	Oxidized	8.3	19.5	18.0	A-6(11)
36-1	"	0.8	63.2	36.0	28.9	0.21	1.8	Oxidized	6.7	21.0	20.7	A-7-6(13)
43½-1	"	0.4	60.2	39.4	33.0	0.37	0.5	Oxidized	6.7	24.4	33.4	A-7-6(18)
46-1	"	0.8	55.7	43.5	36.2	0.30	1.5	Oxidized	6.3	22.6	32.7	A-7-6(19)
49-3	Loveland (soil)	2.7	61.1	36.2	31.4	0.19	1.3	Oxidized	8.2	22.7	24.6	A-7-6(15)
49-4	Loveland	5.3	65.9	28.8	24.6	0.11	7.0	Oxidized	8.2	16.6	15.3	A-6(10)

^aSand—2.0 to 0.05 mm., silt—0.05 to 0.005 mm. One micron equals 0.001 mm.

^bBureau of Public Roads Soil Classification System. Also referred to as the Highway Research Board System or the American Association of State Highway Officials (AASHO) System (7).

the different particle-size fractions of the loess has not as yet been determined. The pH values varied from 6.7 to 8.7 or from near neutral to alkaline. The variations in whole loess cation exchange capacity, in plasticity index, and in B.P.R. classification are mainly due to the variation in clay content (2).

CLAY FRACTION

The minus 2 micron portions of the whole loess samples were used for the exchange capacity determinations because practically all of the cation exchange material, the clay minerals, occur in this particle-size range. Complete separation of the clay minerals from other substances such as quartz and carbonates is difficult, but only very small amounts of such substances are commonly found in the minus 2 micron soil fraction.

The separation of the minus 2 micron clay material from the whole loess was by means of a sedimentation procedure which is the subject of another paper now in preparation. In this procedure neither the whole loess nor the separated clay was given hydrochloric acid or hydrogen peroxide treatments. When a deflocculating agent was needed to prevent flocculation, 0.1 N sodium hydroxide was used.

DETERMINATION OF CATION EXCHANGE CAPACITY

Cation exchange capacity can be determined by a number of methods, most of which involve leaching the soil sample with a salt solution containing known cations followed by analysis either of the resulting soil or of the solution for the amount of cations exchanged. Because of solubility and decomposition effects Kelly and Brown (8) recommended the determination of the cations absorbed by the soil rather than of the amount of cations that are brought into solution from the soil.

The cation exchange capacity of a soil denotes the total amount of cations that can be exchanged under a given set of conditions and not necessarily the amount that could be exchanged under other conditions. The determination is particularly sensitive to the pH of the salt solution; the common practice is to use a neutral (pH = 7) solution. Neutral normal ammonium acetate has been found to be a salt solution especially well adapted to the exchange capacity determination (9). With this solution the exchange capacity of inorganic soils can be determined with reasonable accuracy even when the soil contains soluble salts and calcium carbonate.

Test methods used in determining cation exchange capacities of whole Wisconsin loess samples have been previously presented by

the authors (2). A step-by-step summary of the procedure used in the present study is as follows:

1. Weigh out about one gram (accurate to 1 mg) of representative air-dry clay and place in a 300 ml centrifuge bottle. (A similar sample should be weighed out for the hygroscopic moisture determination needed to convert air-dry weight to oven-dry weight.)
2. Add 10 g of fine Ottawa sand to the clay in the centrifuge bottle. (Ottawa sand is inert and increases the permeability for the purpose of filtration in Step 7.)
3. Add 250 ml of neutral normal ammonium acetate to the contents of the centrifuge bottle and shake for 3 min. (Higher normalities and increased shaking times were experimented with but did not significantly affect results.)
4. Centrifuge at 2000 RPM for 10 min.
5. Decant the clear supernatant liquid.
6. Repeat Step 3.
7. Filter the contents of the centrifuge bottle with a Buchner funnel containing two fine filter papers.
8. Wash the material retained on the filter paper with 150 ml of neutral 70 percent (by volume) methyl alcohol to remove the excess ammonium acetate trapped in void spaces.
9. Determine the amount of ammonia held in the exchange positions of the clay by a modified Kjeldahl nitrogen determination (2).
10. Calculate the cation exchange capacity in milliequivalents per 100 g of oven-dry clay (2).

CATION EXCHANGE CAPACITIES

Cation exchange capacities of minus 2 micron clay fractions are given in Table III. Since the clay minerals are the primary seat of cation exchange, the uniformity of the exchange capacity data

Table 3
Cation Exchange Capacities of Minus 2 Micron Clay Fractions

Sample no.	Material	Age Classification	Cation Exchange Capacity ^a (m.e./100g)
55-1	Loess	Upper Wisconsin	59.3
20-2	"	Wisconsin (Undifferentiated)	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
49-3	Soil	Loveland	63.4
49-4	Loess	"	54.4

^aValues reported are the average of two determinations.

indicates that there is little variation in the kinds of clay minerals in the Wisconsin Loess. The data further indicates that there is little difference between the clay fractions of the Wisconsin loess and the Loveland Loess. The results of differential thermal analyses on whole loess samples (3) substantiate this interpretation.

Slight variations in the cation exchange capacity values in Table III may or may not be significant. Further studies are in progress to determine whether they are due to experimental factors or to slight variations in mineral composition.

The clay fractions extracted from soils are rarely composed of a single kind of clay mineral but usually contain two or more mixed with other substances from which complete separation is difficult. The exchange capacity of the minus 2 micron particle-size range for this reason can at best be used only to estimate roughly the predominant kind of clay mineral present. The estimation can be made by comparing the determined value with the exchange capacities of comparatively pure clay minerals. Grim (10) gives cation exchange capacities of the common clay minerals as:

Montmorillonite.....	60-100 m.e./100g
Attapulgite.....	25-30
Illite.....	20-40
Kaolinite.....	3 -15
Halloysite.....	6 -10

A comparison of the data in Table III with Grim's values indicates that the loess clay fractions contain a predominance of montmorillonite group minerals. Differential thermal curves for samples of whole loess from southwestern Iowa have indicated the presence of illite (3). This mineral is often associated with montmorillonite in soils, and its presence would tend to lower the exchange capacity (9).

According to Jackson et al (11), montmorillonite can develop from illite by weathering, which may be the reason why the Loveland soil has a higher exchange capacity than the loess on which it developed. The same explanation may apply to the difference in the exchange capacities of samples 26-1 and 26-2. The oxidized and leached sample (26-1) had a slightly higher exchange capacity than the unoxidized and unleached sample (26-2).

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