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CHARACTER OF THE COLLOIDAL MATERIALS IN THE PROFILES OF CERTAIN MAJOR SOIL GROUPS

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INTRODUCTION

Considerable information is available regarding the composition and properties of colloids from soils of widely differing character. Emphasis has been placed on the study of colloids from the more important soil types, and such studies have for the most part been confined to materials isolated from one, or at most two, horizons of a profile. Some investigations have, however, increased the scope of this work to include a few complete profiles. In recent years much emphasis has been placed on the character of soil materials in the various horizons of complete soil profiles and on the nature of the processes whereby horizon development takes place. However, little attention has been given to the effect of soil-making processes on the character of the resulting colloids in various horizons of the profiles. In the present study data are obtained which indicate the character of the colloidal materials developed throughout the profile as a result of a dominating influence of one of the major soil-making processes in developing a typical profile. Three of these soil-making processes, which have been widely recognized, are calcification, podsolization, and lateritization. These processes lead respectively to the formation of pedocals, podsols, and laterites.

The general plan of the investigation was to secure typical profiles of the several major soil groups and to isolate and study colloidal material from each of the horizons. Chemical analyses and

a study of properties were made of each in order to bring out as well as possible similarities and differences in the colloidal materials which are characteristic of the various horizons and of the different soil groups.

PREVIOUS WORK

Very few data are available regarding the character of the colloidal materials in typical profiles of any of the major soil groups mentioned. Most of the soil-colloid studies previously made have been done without any reference to the processes by which the soils were developed and, with few exceptions, without consideration of the horizon in the soil profile from which the sample was taken. Similarity of colloidal materials in various horizons of most profiles appears to be the general rule. This is indicated by the study of materials from a considerable number of soils and subsoils by Robinson and Holmes (*30*).[1] A detailed study by Holmes (*17*) of several complete profiles of the Leonardtown soil series from different localities led to a similar conclusion, as does also the work on the Cecil, Chester, and Miami soil series by Holmes and Edgington (*18*).

Denison (*11*) gives the chemical composition of colloids from several horizons of profiles of widely diversified character. Included in this group are a podsol profile from Michigan and a chernozem from South Dakota. The horizons of the podsol reported are the A_1, B_3, and C_2. The parent material is highly calcareous. In this profile the colloids are fairly uniform in the major elements of composition. The silica-sesquioxide ratio is, however, somewhat lower in the B_3 horizon than in the A_1 or C_2. The chernozem profile shows about the same silica-sesquioxide relationship within the profile as that shown by the podsol. Deep horizons of certain piedmont soils show unusually low silica-sesquioxide ratios. The work of McCool (*23*) with certain Michigan soils showed no very marked differences in the colloid throughout the profile, although some of these are podsolic in character. There was, however, a tendency toward higher silica content and higher heat of wetting in the colloids of the B horizons than in the colloids either above or below this layer.

Although similarity of colloids from different horizons of a particular profile appears to be the rule for many widely diversified soils, instances have been reported of colloids from profiles where certain horizons show rather wide differences in character of colloid. In his exhaustive report on the forest soils of northern Sweden, many of which are true podsols. Tamm (*31*) gives the chemical composition of fractions below 0.002 millimeter in diameter for the bleached layers and for the ortsteins of two of these soils. These fractions may be assumed to consist essentially of colloidal material. If the silica-sesquioxide ratios be taken as indices of the major features of chemical composition, considerable differences are noted in the horizons. Calculations made from Tamm's data show these ratios to be 3.44 and 4.16 for fractions from the bleached layers, and 2.63 and 2.10 for fractions from the corresponding ortsteins.

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[1] Italic numbers in parentheses refer to Literature Cited. p. 23.

The data available regarding the colloids of true laterites are too fragmentary to allow of any conclusion regarding colloid variation throughout the profile. The same is true of the pedocal group of soils. There is, however, some evidence that colloidal $CaCO_3$ is relatively inert in properties.[2]

DESCRIPTION OF SOIL SAMPLES

The soil samples used in the present studies were collected by various members of the field staff of the soil survey division of this bureau under the general direction of C. F. Marbut. General characteristics of the various soil classes and detailed descriptions of the profiles studied follow. One pedocal, two podsols, and three lateritic soils are discussed.

The calcification process results in the formation of the pedocal [3] group of soils, an important division of which includes the chernozems. These are found in regions of moderate to low rainfall and are characterized by the accumulation of calcium carbonate in the lower horizons. Profile No. 1 is a specimen of this class. It is an Amarillo silty clay loam which is representative of the southern chernozems. Samples were collected by E. H. Templin 1 mile east of Nash, Potter County, Tex. Horizon 1 [4] is of rich-brown color with a faint tint of red; horizon 2 is dark brown, slightly lighter in color than horizon 1; horizon 3 is of yellowish-brown color; horizon 4 shows a marked contrast in color to the above horizons, being a reddish yellow; horizon 5 is yellowish white with a very faint pink shade; and horizon 6 is somewhat more pink than horizon 5.

The general character of profiles of the so-called podsol soils has been widely discussed by soil investigators. The podsols are forested soils occurring in northern latitudes. A typical profile of this class of soils may be summarized as follows: The surface layer consists of a covering of decomposing leaves and other organic remains which are distinctly acidic in character. Below this is a bleached layer usually gray in color and of lighter texture than the layer beneath it. This layer is commonly known as bleicherde. It is underlain by a rust-colored or brown layer which in many places takes the form of a hardpan and is commonly referred to as the ortstein, or the orterde if not indurated. The cementing material may be of high iron content, high in organic matter, or a mixture of relatively large quantities of each. Below the ortstein is the parent material.

Two typical podsol profiles were obtained for study. Detailed descriptions of these profiles are as follows: Profile No. 2 is a Superior fine sandy loam. It was collected by W. J. Geib near Bayfield, Wis., from a wood lot of virgin soil. The A_0 horizon, 0 to 3 inches in

[2] McCool, M. M., and Wheeting, L. C. STUDIES ON THE COLLOIDAL MATERIAL OF CERTAIN SOIL PROFILES IN MICHIGAN. Amer. Soil Survey Assoc. Rpt. Ann. Meeting 5, Bul. 6, v. 2, p. 122–126c. illus. [Mimeographed.]

[3] The term " pedocal " has been used by Marbut (25) to designate those soils which have " fully developed profiles in which lime carbonate is found in some horizon of the solum in higher percentage than in the parent geological formation beneath."

[4] The term " horizon " is used here to designate a layer in the profile different in some respect from the layers above and below it and has no reference to the usual differentiation of the profile into the conventional A, B, and C horizons. This is true in general in this bulletin except where such designations are used.

depth, consists of partly decayed leaves and other organic matter and has a dark-brown color. The A_1 horizon occurs from a depth of 3 to 8 inches; its color is gray with a very slight pink tint. The B horizon, between depths of 12 and 30 inches, ranges from light to dark coffee brown in color and is compactly cemented. The C horizon, extending from a depth of 30 to 40 inches, is of pinkish-gray color. It rests on heavy red clay.

Profile No. 3 is a Beckett loam collected by W. J. Latimer in a virgin-forest area 1 mile west of Washington, Mass. The A_0 horizon, from 0 to 6 inches, is of dark-brown color and contains a large amount of leaf mold and roots. The A_1 horizon, from 6 to 11 inches, is essentially gray in color but contains some brown spots. The B_1 horizon is a thin dark-brown or coffee-colored layer, extending from a depth of 11 to 13 inches. The B_2 horizon extends from a depth of 13 to 24 inches and is yellowish brown, grading to pale yellowish brown. Both the B_1 and B_2 horizons are friable. The C horizon, or parent material, taken between depths of 24 and 36 inches, is of yellowish-gray color mottled and streaked with brown.

Laterite soils consist primarily of hydrated oxides or hydroxides of iron or alumina, or both, in the upper horizons. In typical profiles, according to Harrassowitz (*14*), this material is underlain first by a mottled zone and then by a layer of kaolin or kaolinlike material above the parent rock. In general, lateritic soils are characterized by a decrease in the silica-sesquioxide ratio from that existing in the parent rock.

Typical laterite profiles are not easily obtainable. In the present case it was necessary to use material not entirely typical in a complete profile, but by the use of three profiles the various classes of materials are represented. Profile No. 4 is a Davidson clay loam soil, lateritic in character, collected by R. C. Jurney, 9 miles north of Greensboro, N. C. Horizon A is 0 to 9 inches in depth, and its color is slightly reddish brown. The B_1 horizon, extending from 9 to 36 inches in depth, is a deep-red heavy brittle clay. Below this is the B_2 horizon, between 36 and 60 inches, which is light-red friable crumbly clay. The C horizon, which lies below 60 inches, is an ocherous-yellow, black, and reddish-brown decomposed diorite rock.

Profile No. 5 is a ferruginous laterite which was obtained near Preston, Cuba. The sample was collected through the courtesy of the United Fruit Co. from an area previously located by H. H. Bennett of this bureau. The first horizon, from 0 to 12 inches, is very dark-red friable clay material containing a few concretions. A second horizon, extending from a depth of 40 to 60 inches, is reddish yellow and of about the same texture as the horizon above.[5] A third horizon, from 100 to 144 inches, is almost identical in color and texture with the first horizon.

Profile No. 6 is an aluminous laterite from a bauxite mine at Bauxite, Ark. This profile can not, strictly speaking, be regarded as a soil since an overburden of some 30 to 40 feet of transported material had been removed, material which had no particular rela-

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[5] A communication from C. F. Marbut states that in this locality material similar to that of the second horizon usually persists to an indefinite depth.

tion to the profile of interest for the present work. However, this profile contains material similar, in chemical composition at least, to profiles of typical laterites found in certain parts of the world.

MECHANICAL AND CHEMICAL COMPOSITION OF SOILS

In order to obtain more adequate information regarding the character of the soils which were to serve as sources of the colloids, mechanical and chemical analyses were made. Mechanical analyses were made by the method in use in this bureau (28). The results are given in Table 1. Chemical analyses were made by well-authenticated methods for total constituents, methods which have long been in use in this bureau. These analyses are given in Table 2.

TABLE 1.—*Mechanical analyses of soils* [1]

Profile No.	Soil series	Depth	Horizon	Fine gravel, 2.0-1.0 mm.	Coarse sand, 1.0-0.5 mm.	Medium sand, 0.5-0.25 mm.	Fine sand, 0.25-0.1 mm.	Very fine sand, 0.1-0.05 mm.	Silt, 0.05-0.005 mm.	Clay, <0.005 mm.	Inorganic in colloid, <0.002 mm.	Loss on treatment with H₂O₂
		Inches		Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.
1	Amarillo____	0-5	1	0.0	0.2	0.3	2.6	12.1	55.1	27.6	23.9	2.0
		10-20	2	.0	.1	.2	1.9	8.3	41.0	47.4	42.8	1.1
		30-40	3	1.0	.5	.4	1.6	6.9	45.2	43.8	37.6	.5
		54-64	4	.1	.3	.4	3.4	16.6	41.2	37.9	34.6	.3
		70-75	5	.1	.4	.4	2.2	9.2	34.1	53.4	35.9	.2
		96-100	6	.2	.2	.3	2.1	12.2	41.0	44.0	31.3	.0
2	Superior____	0-3	A₄	.3	2.9	4.3	24.7	7.3	16.8	3.0	1.5	40.6
		3-8	A₁	.3	2.0	7.5	52.5	12.5	20.1	4.0	1.6	1.3
		12-30	B	7.1	34.7	33.0	13.5	.8	2.0	7.1	4.9	1.2
		30-40	C	1.5	13.8	50.4	28.6	.9	1.6	3.1	2.6	.2
3	Beckett_____	0-6	A₀	2.1	7.2	5.0	17.4	15.1	18.6	2.6	.9	31.3
		6-11	A₁	2.6	5.9	7.2	23.2	18.3	33.8	7.0	3.9	2.0
		11-13	B₁	2.3	5.3	6.7	21.6	16.7	28.7	9.6	5.8	9.1
		13-24	B₂	3.1	5.5	6.0	21.2	18.4	30.2	9.0	5.5	5.6
		24-36	C	3.4	6.8	8.4	25.8	19.1	26.2	8.9	5.5	1.4
4	Davidson___	0-9	A	.7	2.3	2.6	9.6	16.7	29.4	34.3	25.9	4.4
		9-36	B₁	.1	.7	.9	5.4	8.9	22.3	60.4	54.0	1.3
		36-60	B₂	.3	1.0	.9	7.2	9.1	30.4	50.3	41.3	.3
		84-96	C	.4	1.3	1.9	14.3	17.5	34.5	29.6	23.7	.5
5	Nipe_____	0-12	1	4.6	4.1	2.0	2.3	1.6	21.2	63.9	50.2	.3
		40-60	2	3.9	6.1	3.8	6.1	4.0	16.3	61.1	56.3	.0
		100-144	3	4.0	4.2	2.1	2.3	1.3	21.7	64.0	50.4	.5
6	Bauxite, soft	150-214	4	19.3	15.9	6.6	8.5	5.0	25.5	17.8	11.8	1.5
	Kaolinized__	250-290	6	.2	.7	.7	2.4	3.6	38.9	53.1	35.2	.3

[1] Determinations by L. T. Alexander and Hubert W. Lakin.

Table 2.—*Chemical composition of soils* [1]

Profile No.	Soil series	Depth	Horizon	SiO2	Al2O3	Fe2O3	MnO	CaO	MgO	K2O
		Inches		Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
1	Amarillo	0-5	1	75.02	10.56	3.16	0.09	0.67	0.75	2.20
		10-20	2	70.48	13.88	4.40	.09	.97	1.35	2.56
		30-40	3	68.72	13.25	4.31	.08	2.64	1.37	2.48
		54-64	4	74.40	11.67	3.83	.08	1.09	1.10	2.14
		70-75	5	40.42	6.09	2.04	.04	25.80	1.04	1.20
		96-100	6	58.71	.04	2.86	.06	14.11	1.22	1.71
2	Superior	0-3	A0	51.50	3.30	1.44	.08	1.29	.32	1.25
		3-8	A1	80.51	3.55	1.36	.01	.44	.13	2.15
		12-30	B	88.24	4.27	2.59	.01	.30	.40	1.61
		30-40	C	92.03	3.77	1.12	.01	.20	.23	1.30
3	Beckett	0-6	A0	52.95	7.04	1.08	.01	.90	.15	2.06
		6-11	A1	83.32	6.73	1.09	.01	.54	.18	2.89
		11-13	B1	69.60	8.61	3.99	.01	.65	.33	3.41
		13-24	B2	72.67	10.32	3.58	.02	.63	.41	3.45
		24-36	C	77.86	10.00	3.15	.03	.54	.48	3.70
4	Davidson	0-9	A	70.53	12.45	6.10	.22	.75	.45	.58
		9-36	B1	52.70	22.87	10.62	.07	.51	.40	.45
		30-60	B2	50.53	23.05	14.87	.08	.27	.58	.34
		60+	C	52.62	20.98	13.37	.47	.27	1.00	.72
5	Nipe	0-12	1	7.96	14.71	64.00	1.09	.41	.27	Trace.
		40-60	2	4.36	9.49	67.51	.44	.02	.27	.04
		100-144	3	11.03	15.23	55.22	.40	Trace.	.53	.12
6	Bauxite	156-214	4	4.45	55.14	6.23	.19	.04	.04	Trace.
		250-290	6	43.87	38.92	2.32	.26	.02	.02	.21

Profile No.	Soil series	Depth	Horizon	Na2O	TiO2	P2O5	SO3	Ignition loss	N	pH
		Inches		Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	
1	Amarillo	0-5	1	1.06	0.78	0.10	0.07	4.08	0.13	6.5
		10-20	2	1.01	.71	.09	.07	4.94	.08	7.8
		30-40	3	1.03	.74	.10	.06	5.50	.06	7.8
		54-64	4	.87	.95	.07	.21	3.82	.02	7.0
		70-75	5	.46	.42	.08	.13	21.82	.01	7.9
		96-100	6	.73	.57	.09	.11	13.00	.01	8.3
2	Superior	0-3	A0	.24	.25	.18	.33	39.77	1.17	4.7
		3-8	A1	.34	.34	.02	.07	1.83	.04	5.1
		12-30	B	.15	.19	.17	.05	1.94	.03	5.6
		30-40	C	.30	.10	.04	.03	.84	.01	5.6
3	Beckett	0-6	A0	.40	.66	.13	.36	34.40	1.04	3.8
		6-11	A1	.46	.90	.04	.13	2.75	.05	3.7
		11-13	B1	.46	.70	.08	.20	11.25	.14	3.9
		13-24	B2	.67	.70	.08	.14	7.27	.09	4.1
		24-36	C	.55	.53	.08	.13	2.54	.02	4.5
4	Davidson	0-9	A	.00	1.50	.10	.12	7.66	.11	6.3
		9-36	B1	.00	1.39	.12	.12	10.55	.02	5.1
		30-60	B2	.00	1.47	.20	.12	9.37	.01	4.4
		60+	C	.00	1.23	.24	.09	9.15	.01	4.1
5	Nipe	0-12	1	.03	.73	.04	.24	10.12	.08	5.4
		40-60	2	Trace.	.53	.01	.38	12.45	.00	5.0
		100-144	3	.15	.86	.05	.25	12.28	.12	5.4
6	Bauxite	156-214	4	.02	2.25	.14	1.20	36.43	.00	3.6
		250-290	6	.01	1.26	.03	.26	13.19	.00	3.0

[1] Determinations by G. H. Hough and G. E. Edgington.

Certain characteristic features of each group of soils are apparent from their mechanical and chemical compositions. In the case of pedocal soils that part of the profile which shows the presence of calcium carbonate gives a suggestion as to the general class to which the soil belongs. However, comparable quantities of calcium carbonate may be present in soils in the process of formation from calcareous parent material. In such cases lower pH values may usually be expected in the upper horizons than when the calcification process is in action in the profile.

In the case of profiles Nos. 2 and 3 the excessively high organic content of the A_o horizon (indicated from the nitrogen content and from the loss on treatment with hydrogen peroxide) compared with that of the lower horizons is immediately suggestive of the podsol class. To some extent the translocation of sesquioxides or organic matter or both from the A horizons to the B horizons are recognizable from the whole soil. This feature has been previously noted (12).

Typical laterites are the one group of soils easily recognizable by their chemical composition. The high content of sesquioxides, particularly at the surface, serves to characterize this group. In the case of lateritic or partly lateritized soils the chemical composition shows less marked evidence as to class.

Although the chemical composition of whole soils is to some extent diagnostic in indicating the general group to which a soil may belong, such interpretations from analyses are subject to sharp limitations. The character of the colloid is of particular significance, and variations in its composition may be much obscured by the varying mechanical composition of whole soil.

METHODS OF STUDY OF COLLOIDAL MATERIALS

Colloidal materials were extracted from each of the soils in a manner somewhat similar to that previously described (13). The separation of colloid was made by the use of a high power centrifuge, 0.001 mm. being taken as the upper limit of particle size of the colloid. No attempt was made to extract all of the colloid present. However, each soil was extracted several times with large quantities of water, and the bulk of the easily dispersable colloid was separated. Several of the soil samples presented unusually difficult problems of dispersion. In cases where necessary a deflocculant was used. In most cases ammonium hydroxide was a satisfactory deflocculant. However, this did not produce dispersion of horizon No. 4 of profile No. 6. In this case long washing with water and subsequent treatment with sodium oxalate was found satisfactory. This treatment was necessary because of the presence of soluble aluminum sulphate and the high content of aluminum hydroxide.

Chemical analyses were made by the standard methods employed in this bureau for total constituents.

The heat of wetting was determined by the method described by Anderson (4). Determinations of this value for a few of the colloids which were exceedingly high in organic matter are not included, owing to the fact that they were only slightly wetted by water. Most of the powder floated on the surface even after vigorous stirring. The heat of wetting, of course, could have been determined in certain organic liquids, but it has been previously shown that no fixed relationship exists between heat of wetting of soil colloids by water and by alcohol or benzene (5).

The moisture-equivalent determination was carried out essentially according to the procedure described by Briggs and McLane (9) for soils.

The adsorption of water vapor was determined over 3.3 per cent sulphuric acid and over 30 per cent sulphuric acid (29, 7). The two

sets of values have different significance. The adsorption value obtained for soil over 3.3 per cent acid is frequently used as a basis for determining approximate colloidal content, owing to the fact that the colloidal materials of most soils show little variation from an average of about 30 per cent adsorption of water over this strength of acid (29). These values, in addition to being presented in the tables, are also used as a basis of calculation of the approximate total quantity of colloid in the soil as outlined in this previous publication (29). Also in the process of mechanical analysis of soils, two values are obtained, the sum of which in most cases expresses the colloid with fair approximation. These are the mechanical fraction below 0.002 millimeter and the loss of weight by treatment with hydrogen peroxide. In the case of rather unusual horizons, such as are largely organic or highly lateritic, these methods give divergent results.

The contents of exchangeable monovalent and divalent bases were determined by treating the colloids with normal ammonium chloride solutions essentially according to the method of Kelley and Brown for soils (21). In the case of colloids containing calcium carbonates a procedure essentially as recommended by Magistad and Burgess (24) was used. This method employs ammonium chloride in 68 per cent alcohol instead of in water. In this procedure smaller quantities of calcium carbonate are dissolved than when water is used. In the present work no correction was made for the approximate solubility of calcium carbonate in salt solutions. The determination of exchangeable bases was omitted in a few cases where the contents of total bases shown by analysis were so small that probable error of the determinations would render the results of little significance.

Base-exchange capacity was determined essentially as described by Holmes (17), except that washing was done by means of Pasteur-Chamberland filters instead of on paper as it was found that some of the materials used in this study could not be properly washed on paper filters. Samples of about 4 grams each were treated with 100 cubic centimeters of normal barium chloride solution which had been adjusted to pH 7. After standing overnight the liquid was drawn off through the filters and washed with successive portions of barium chloride solution until the filtrate amounted to about 500 cubic centimeters. In order to remove the excess of barium chloride the samples were washed with water until free from chlorides. The barium held by the colloid was then extracted by means of 0.05 N HCl. In case of the colloids containing $CaCO_3$ the barium was removed by normal ammonium chloride instead of hydrochloric acid. In either case the barium in the filtrate was determined as sulphate.

The degree of saturation is calculated as a percentage of total capacity from the exchangeable monovalent and divalent bases, found by analysis, and the base capacity, shown by the barium chloride determination. It is recognized, of course, that this procedure, while standard, does not actually represent the replaceable bases and the hydrogen of the soil colloid but does to a marked degree make comparison of the varying colloids subjected to it.

For convenience the characteristics of the colloids of each soil group will be discussed separately.

CHARACTER OF PEDOCAL COLLOIDS

The characteristic process of pedocal formation consists in the conversion of calcium to the carbonate and its ultimate deposition in the form of the carbonate at varying depths below the surface. The influence of organic matter at the surface is assumed to be an important factor in this process. Carbon dioxide from organic decomposition aids in the solution of calcium as the bicarbonate. The low rainfall of these regions does not, as a rule, allow extensive percolation to great depths, and hence a deposit is formed, consisting essentially of calcium carbonate, at a position approximating the depths to which surface waters most frequently percolate. It is not necessary to assume, however, that all the calcium carbonate of the calcareous horizons came from the overlying strata. It is frequently assumed that materials may rise in the capillary water from lower strata and be precipitated in the zone of calcification. Previous studies have indicated that the colloids from surface soils of such regions tend to have relatively high silica-sesquioxide ratios.

The chemical composition of the colloids extracted from each horizon of a soil of this group, designated as profile No. 1, are given in Table 3. Properties of the same series of colloids are given in Table 4.

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TABLE 3.—*Chemical composition of pedocal soil colloids,[1] profile No. 1, Amarillo soil series*

Depth	Horizon	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	MgO	K_2O	Na_2O	TiO_2	P_2O_5	SO_3	CO_2	Ignition loss	Organic [2] matter	Mols $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$
Inches		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
0–5	1	50.51	22.04	8.80	0.14	1.48	2.08	2.68	0.06	0.56	0.20	0.18	None.	12.08	4.02	3.10
10–20	2	51.51	22.71	8.61	.09	1.59	2.66	2.54	.01	.57	.12	.14	None.	9.50	2.14	3.09
30–40	3	51.32	22.43	8.46	.05	2.27	2.80	2.50	.06	.58	.14	.14	.35	10.19	1.96	3.13
54–64	4	51.23	24.08	8.19	.07	1.73	2.83	2.42	.10	.55	.11	.13	None.	8.72	.96	2.97
70–75	5	38.42	17.64	5.71	.06	16.38	2.53	1.83	.06	.37	.09	.10	11.22	17.85	.42	3.06
96–100	6	45.88	20.09	6.89	.05	9.05	2.87	2.26	.01	.52	.11	.13	5.87	12.41	.13	3.18

[1] Chemical analyses by G. E. Edgington.　　　　[2] Determined by combustion, $CO_2 \times 0.471$.

TABLE 4.—*Properties of pedocal soil colloids, profile No. 1, Amarillo soil series*

Depth	Horizon	Heat of wetting per gram of colloid	H_2O vapor adsorbed over 30 per cent H_2SO_4 per gram of colloid	H_2O vapor adsorbed over 3.3 per cent H_2SO_4 per gram of colloid	Moisture equivalent	Exchangeable bases per gram of colloid					Exchangeable base capacity per gram of colloid by $BaCl_2$	Degree of saturation	Colloid content of soil determined by H_2O adsorption	Colloid content by mechanical analysis	Colloid extracted from soil	Mols $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$
						Ca	Mg	K	Na	Total						
Inches		*Calories*	*Gram*	*Gram*	*Per cent*	*Milliequiv- alents*	*Milliequiv- alents*	*Milliequiv- alents*	*Milliequiv- alents*	*Milliequiv- alents*	*Milliequiv- alents*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
0–5	1	16.8	0.154	0.300	84.3	0.389	0.159	0.034	0.006	0.588	0.566	(1)	25.7	25.9	18.2	3.10
10–20	2	18.5	.184	.340	85.0	.492	.149	.030	None.	.671	.628	(1)	39.1	43.9	10.5	3.09
30–40	3	18.0	.182	.334	85.6	.628	.154	.015	.019	.816	.634	(1)	35.9	38.1	13.8	3.13
54–64	4	19.5	.201	.363	88.5	.532	.149	.019	.026	.726	.692	(1)	30.3	34.9	10.0	2.97
70–75	5	13.8	.147	.292	78.9	1.027	.099	.017	None.	1.143	.656	(1)	24.1	36.1	10.5	3.06
96–100	6	18.0	.171	.331	86.6	.924	.099	.015	.009	1.047	.700	(1)	26.2	31.3	14.7	3.18

[1] Saturated.

Colloids developed in the Amarillo profile show uniformity of composition to a marked degree in all respects except in their content of calcium carbonate. This constancy of composition of major constituents throughout the profile is indicated by the small variation in silica-sesquioxide ratios, which range from 2.97 to 3.18. The unique feature of this class of profiles lies in the extent to which calcium carbonate is found in the colloids of the lower horizons.

Most of the property values for colloids of this profile are high, and their magnitudes are essentially of the order that should be expected from their silica-sesquioxide ratios. The only important deviation from regularity is in horizon 5, where the calcium carbonate content is about 25 per cent of the dry weights of the colloids. In this horizon the colloidal property values are lower than the mean for the profile by approximately the amount of calcium carbonate present, indicating that this material is essentially inert so far as such properties as heat of wetting and water adsorption are concerned. The inert character of colloidal calcium carbonate is in accordance with earlier observations in this bureau and elsewhere.[6]

CHARACTER OF PODSOL COLLOIDS

The podsolization process is usually regarded as essentially one of solution, true or colloidal, with subsequent transportation of the products of solution although other weathering alterations may also be taking place. This is in contrast to progressive weathering whereby partly decomposed residual products left in place predominate as is the case when calcification is in progress. Most of the dissolved materials are hydrolyzed, and the more soluble constituents pass into the drainage water, whereas the less soluble products are moved to lower horizons. It is a process involving movement of colloidal constituents, as well as more soluble nutrients, downward, leaving an impoverished upper layer. The mechanism of the action whereby the sesquioxides and organic matter move downward and are deposited in the B horizon is a matter which has been carefully investigated but not accounted for in an altogether satisfactory manner.

Data showing the accomplishment of the podsolization process as affecting the chemical compositions throughout the profile are given in Table 5, and properties of the same materials are given in Table 6.

[6] McCOOL, M. M., and WHEETING, L. C. Op. cit.

TABLE 5.—*Chemical composition of podsol colloids [1] of Superior and Beckett soils*

Profile No.	Soil series	Depth	Horizon	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	MgO	K_2O	Na_2O	TiO_2	P_2O_5	SO_3	Ignition loss	Organic matter [2]	Organic matter [3]	Mols $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$
		Inches		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
2	Superior	0–3	A_0	20.89	7.51	3.04	0.10	1.74	1.05	0.79	0.26	0.34	0.50	0.81	63.15	57.52	61.5	3.76
		3–8	A_1	46.20	16.67	4.55	.08	1.01	1.25	2.14	.34	.97	.39	.35	25.58	19.70	19.9	4.01
		12–30	B	31.60	25.14	13.47	.08	.66	1.71	1.37	.15	.88	.96	.18	23.35	9.96	9.6	1.59
		30–40	C	42.20	22.62	12.31	.12	.61	3.41	1.23	.06	1.57	.31	.17	15.59	5.35	5.9	2.40
3	Beckett	0–6	A_0	10.58	5.99	3.64	.02	.65	.31	.49	.25	.49	.31	.99	75.87	69.98	68.1	2.16
		6–11	A_1	38.39	20.26	5.55	.02	.40	1.03	2.51	.24	1.48	.25	.23	29.25	26.78	22.2	2.74
		11–13	B_1	13.40	12.02	22.38	.10	.32	.65	.83	.12	.90	.60	.44	47.90	39.05	40.4	.86
		13–24	B_2	21.56	20.06	13.02	.06	.16	1.18	1.98	.28	.74	.37	.35	39.78	30.34	32.3	1.28
		24–36	C	34.31	27.55	11.60	.01	.17	2.10	4.10	.25	.72	.18	.19	18.82	9.48	9.6	1.67

[1] Chemical analyses by G. E. Edgington. [2] Determined by combustion, $CO_2 \times 0.471$. [3] Determined by loss on treatment with H_2O_2.

TABLE 6.—*Properties of podsol colloids of Superior and Beckett soils*

Profile No.	Soil series	Depth	Horizon	Heat of wetting per gram of colloid	H_2O vapor adsorbed over 30 per cent H_2SO_4 per gram of colloid	H_2O vapor adsorbed over 3.3 per cent H_2SO_4 per gram of colloid	Moisture equivalent	Exchangeable bases per gram of colloid — Ca	Mg	K	Na	Total	Exchangeable base capacity per gram of colloid by $BaCl_2$	Degree of saturation	Colloid content of soil determined by H_2O adsorption	Colloid content of soil by mechanical analysis	Colloid extracted from soil	Mols $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$
		Inches		*Calories*	*Gram*	*Gram*	*Per cent*	*Milli-equivalents*	*Milli-equivalents*	*Milli-equivalents*	*Milli-equivalents*	*Milli-equivalents*	*Milli-equivalents*		*Per cent*	*Per cent*	*Per cent*	
2	Superior	0–3	A_0		0.137	0.410	112.0	0.414	0.124	0.036	0.055	0.629	0.781	80.5	51.1	42.1	1.7	3.76
		3–8	A_1	11.1	.083	.211	86.5	.321	.084	.032	.061	.498	.563	88.5	4.4	2.9	.4	4.01
		12–30	B	16.3	.159	.386	68.1	.200	.064	.013	.003	.280	.440	63.6	6.6	6.1	3.0	1.59
		30–40	C	9.7	.083	.258	70.9	.164	.104	.028	None.	.296	.309	74.2	2.1	2.8	.9	2.40
3	Beckett	0–6	A_0		.162	.350	93.0	.117	.074	.015	.045	.251	.789	31.8	42.3	32.2	2.2	2.16
		6–11	A_1	8.0	.080	.188	91.4	.095	.040	.011	.019	.165	.511	32.3	8.7	5.9	1.5	2.74
		11–13	B_1		.129	.247									33.4	14.9	1.7	.86
		13–24	B_2	8.9	.147	.265	90.8	.061	.025	.008	.026	.120	.537	22.3	16.8	11.1	1.0	1.28
		24–36	C	10.5	.092	.248	83.6	.045	.015	.006	None.	.066	.189	34.9	8.2	6.9	1.5	1.67

Various phases of the process whereby podsolization takes place have been carefully studied by several European investigators. There appears, however, to be still some difference of opinion as to the part played by eluviation and that by solution and subsequent precipitation in the transportation of colloidal materials in a podsol profile. There appears to be little doubt that both processes are operative. Tamm (*31*) believes the transportation of colloidal material in a dispersed condition to be of particular importance. He interprets the process of ortstein formation to be the result of the flocculation by humus of silicic acid, alumina, and iron oxide, which have been transported in the soil as colloidal matter. Albert (*3*) and Aarnio (*1*) have made careful studies of the relation of organic matter to the solution and precipitation of alumina and iron as ions and as colloidal solutions. Albert (*3*)[7] found about the same oxidizing conditions in the A and in the B horizons. From these experiments there appears to be little reason for assuming the solution of ferrous organic compounds in the A horizon and their subsequent precipitation in the B horizon as ferric compounds. From this work the presumption is that the movement is largely mechanical. The work of Aarnio (*1*) emphasizes the importance of the proportions of organic matter in colloids of iron and alumina as determining whether a dispersion or precipitate will result. The present investigation does not presume to answer the question of the nature of the movement of this soil material, nevertheless certain data presented in Table 5 have a bearing on this question and are of interest for brief consideration.

There is abundant evidence in many soils, particularly those of the coastal-plain region which are podsolic in character but not true podsols, that colloidal material may be transported downward mechanically and either filtered out or flocculated in lower horizons. Evidence in support of this explanation lies in the approximate uniformity of character of the colloids in the A and B horizons of such soils, but such evidence is lacking in the true podsols, for there the colloids of the A_1 and the adjoining B horizons show wide differences in chemical composition. Thus it is evident that the colloid has not moved downward in unchanged composition from the A to the B horizons in such cases. Not only is there a marked difference in the ratios of the silica to sesquioxides of the two horizons, but the iron and alumina appear in widely differing proportions as well.

It will be noted in Table 10 (p. 20) that when calculations are made on the basis $SiO_2 + Al_2O_3 + Fe_2O_3 = 100$, there is only a moderate variation in alumina in the B horizons as compared with the A_1 horizons, whereas the increase in iron in the B horizons of the corresponding profiles is enormous. Calculations from these figures show, in the case of the Beckett profile, about 20 per cent less alumina in the colloid of the B horizon than in the A_1 horizon. The iron increase, however, amounts to about 442 per cent. The Superior profile shows a similar contrast although somewhat less marked. The laboratory studies of Aarnio (*1*) indicate that relatively much larger quantities of organic matter are required to precipitate alumina sols than are

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[7] True podsols as understood in this bulletin are developed only under good drainage and free from the influence of ground water.

required for equivalent concentrations of iron preparations. The variation in the precipitation of the two sesquioxides on the basis of these experiments would seem to account for the general character of the differences between the colloids of the A and of the B horizons. There are, doubtless, other factors involved, which further data would help to clarify. For instance, the influence of iron and aluminum ions in a solution as acid as pH 4 is not to be disregarded. Moreover, the reason for extensive colloidal dispersion in a medium as acid as this is not altogether clear.

Property values for colloids of the two podsol profiles show characteristics as variable as those of chemical composition. Each profile shows relatively high values for the colloid of the A_0 horizon, much lower values for the A_1 horizon, and the B values are considerably higher than those of the A_1. The colloid property values throughout the podsol profiles show very different relationships to the major constituents from those ordinarily found. For instance, the A_1 horizons show the highest ratio of silica to sesquioxides, but the property values are low. The colloids of the B horizons have low silica-sesquioxide ratios, but the property values are much higher than those ordinarily associated with this feature of chemical composition. One factor which should be considered in this connection is that the A_1 horizons of both of these soils are of relatively coarse texture and consist chiefly of very fine quartz particles and fragments of organic matter (Table 1), the easily extractable portion of the colloid being very small. Under these circumstances it would not be surprising if appreciable quantities of quartz particles below the limit of 0.001 millimeter in size were not included in the colloid.

Examination of the optical properties of these two colloids by Hendricks and Fry of this bureau (15) showed in each case that no quartz was detectable with the petrographic microscope, but X-ray examination showed its presence to the extent of at least 10 per cent. This might account to some extent for the anomalous properties of these colloids, for it has been shown that some of the properties of colloidal quartz have very small values (4, 6). This is in accord with the somewhat abnormal behavior of the Leonardtown silt loam as reported by Holmes (17).

The high and varying organic content of the colloids of the podsol profiles and the anomalous behavior of these colloids with regard to their major inorganic constituents suggests that organic matter may have an important influence on certain properties. In several cases indirect evidence has shown soil organic matter to be relatively high in base-exchange capacity (16, 22). This does not seem to be true in all cases, however, for Burgess and McGeorge (10) found negligible base-exchange capacity in an organic preparation from an alkali soil.

In view of the high organic content of some of the podsol colloids it was thought desirable to remove the organic matter by hydrogen peroxide and to redetermine certain properties. The complete removal of organic matter from some of these colloids was very difficult, and even its incomplete removal from a sample of any considerable size required enormous quantities of hydrogen peroxide, with frequent removal of the soluble products by washing. In each

case the soluble constituents were finally removed through a Pasteur filter and the residue washed several times with water.

A comparison of the properties of colloids containing large quantities of organic matter and the same colloids after most of the organic matter had been removed by hydrogen peroxide is given in Table 7. Included in this table also is a sample of organic matter prepared from horizon B_2 of the Beckett profile by treatment with strong ammonia and subsequent precipitation with acid.

The removal of organic matter greatly reduced all the property values studied. Calculation of the part contributed by the organic matter to each of the properties shows its influence to be of relatively high magnitude. The data in Table 7 indicates some variability in the organic colloid of the different samples and also some variation in the influence of a particular colloid on different properties. In each case the organic colloid showed higher colloidal properties than the inorganic portion.

TABLE 7.—*Effect of hydrogen peroxide treatment on the properties of soil colloids of Superior and Beckett soils*

Soil series	Depth	Horizon	Treatment	Organic matter content [1]	Base exchange capacity per gram of colloid by BaCl	Adsorption of H_2O over 30 per cent H_2SO_4 per gram of colloid	Heat of wetting per gram of colloid	Calculated base-exchange capacity per gram of organic colloid	Calculated adsorption of H_2O per gram of organic colloid	Calculated heat of wetting per gram of organic colloid
	Inches			*Per cent*	*Milli-equivalents*	*Gram*	*Calories*	*Milli-equivalents*	*Gram*	*Calories*
Beckett	0–6	A0	None	68	0.789	0.162	(2)	1.052	0.231	----------
	0–6	A0	H_2O_2	12	.329	.042	(2)			
	6–11	A1	None	22	.511	.080	8.0	1.024	.157	19.1
	6–11	A1	H_2O_2	3	.386	.047	5.3			
Superior	0–3	A0	None	62	.781	.137	(2)	1.080	.177	----------
	0–3	A0	H_2O_2	8	.356	.080	(2)			
	3–8	A1	None	20	.503	.083	11.1	1.103	.135	26.7
	3–8	A1	H_2O_2	2	.371	.061	6.2			
Superior	12–30	B	None	10	.440	.150	16.3	2.195	.330	46.9
	12–30	B	H_2O_2	None	.245	.140	12.9			
Organic matter from Superior B soil.					1.237					

[1] The approximate organic contents of the H_2O_2 treated samples were computed from the differences between their loss on ignition and the ignition loss of small samples repeatedly treated with H_2O_2 and subsequently washed.

[2] Partly wetted by water.

Although organic matter in the different horizons shows considerable variation in its influence on certain properties, the data in Table 5 indicate fairly close similarity in ultimate composition. This is indicated by the fairly close agreement between the organic content calculated from the carbon dioxide given off on combustion and the organic content indicated by loss on treatment with hydrogen peroxide. No exact correspondence between these values is to be expected because of the uncertainties involved in the use of the Van Bemmelen factor in the combustion method and the probable occurrence of base-exchange phenomena due to both the preservative used in hydrogen peroxide and the ammonia formed in the process.

CHARACTER OF LATERITE AND LATERITIC COLLOIDS

The first stage of the lateritization process is generally assumed to be one of kaolinization. Silicate minerals would, it is assumed, form alkaline solutions by hydrolysis and, under these conditions, a kaolinized product be formed. Under conditions of high temperature and abundant moisture the kaolin is converted by further hydrolysis and the removal of silica to hydrated oxides of aluminum and iron with the simultaneous removal of more soluble silica. Lateritization is therefore signalized by a lowering of the silica-sesquioxide ratio and a high degree of unsaturation of exchange bases. Indeed, as indicated by Martin and Doyne (26), the lateritization may at times keep pace with the kaolinization.

True laterite soils, with their exceedingly high sesquioxide contents, are so distinctive that they are usually distinguishable by a chemical analysis of either the whole soil or colloid. If the whole profile, horizons of which may contain kaolinitic material, be considered, the composition of individual horizons alone might not readily identify this soil group.

The influence of the lateritization process on the character of soil colloids is shown by a study of the colloids from soils of profiles Nos. 4, 5, and 6. The chemical analyses are given in Table 8 and the properties in Table 9. The chemical analyses of the whole soils are also shown in Table 2.

The Davidson profile, No. 4, shows the lateritic process in progress. Sesquioxides are relatively high in proportion to silica but have not yet reached the extreme proportions characteristic of true laterites. The chemical constituents show a high degree of constancy throughout the profile, and property values are of about the magnitude usually found in colloids with similar silica-sesquioxide ratios.

The Nipe profile, No. 5, represents a highly developed ferruginous laterite. The colloid of the first horizon has been previously studied, and most of the data for this horizon given in Tables 8 and 9 are taken from a recent publication (5). The Nipe soil shows the very effective removal of silica by the lateritization process throughout the profile. It will be noted in the case of both this profile and the highly aluminous horizon of profile No. 6 that the colloidal materials show somewhat higher percentages of silica than do the whole soils. This relationship is in contrast to that of most soils, for as a rule colloids are distinctly lower in silica than the soils from which they are extracted. This relationship in the case of laterites is not surprising, since the hydrated oxides of iron and aluminum are usually not easily dispersed and the presence of some silica forms a complex which is often more easily dispersable. Indeed, it is probable that the silica found in the colloid represents the residuum of unhydrolyzed clay.

The silica-sesquioxide ratios of the Nipe colloids are very low, much lower than those of the Davidson. Property values are also low, but such properties as adsorption and heat of wetting are not appreciably different from those of the Davidson colloids, indicating that there is some evidence that minimum values for certain properties may be reached before silica-sesquioxide ratios approach the zero value.

TABLE 8.—*Chemical composition of laterite colloids[1] of Davidson and Nipe soils and bauxite*

Profile No.	Soil series	Depth	Horizon	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	MgO	K_2O	Na_2O	TiO_2	P_2O_5	SO_3	Ignition loss	Mols $\dfrac{SiO_2}{Al_2O_3+Fe_2O_3}$
		Inches		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
4	Davidson	0–9	A	34.43	32.10	12.40	0.24	0.58	0.92	0.50	0.03	0.99	0.25	0.17	17.08	1.46
		9–36	B_1	36.92	31.67	16.03	.06	.56	.41	.37	None.	.92	.18	.12	13.14	1.49
		36–60	B_2	35.37	29.44	20.61	.08	.35	.36	.18	Trace.	.98	.17	.11	12.30	1.42
		60+	C	35.24	29.69	20.10	.30	.50	.06	.17	Trace.	.95	.36	.14	12.53	1.40
5	Nipe	0–12	1	10.19	15.84	62.51	-------	.23	.05	(²)	Trace.	-------	-------	-------	9.86	.31
		40–60	2	5.55	11.47	66.59	.36	(²)	.07	.07	.02	.41	.03	.14	13.51	.17
		100–144	3	12.89	17.93	53.52	.58	(²)	.21	.16	.03	.57	.05	.14	12.70	.42
6	Bauxite	156–214	4	23.83	43.29	7.56	.35	(²)	.09	.02	.08	4.44	.23	.15	19.70	.84
		250–290	6	44.02	39.42	1.83	.10	(²)	.06	.05	(²)	.37	.03	.05	13.93	1.84

[1] Analyses by G. E. Edgington.

TABLE 9.—*Properties of laterite and lateritic colloids of Davidson and Nipe soils and bauxite*

Profile No.	Soil series	Depth	Horizon	Heat of wetting per gram of colloid	H_2O vapor adsorbed over 30 per cent H_2SO_4 per gram of colloid	H_2O vapor adsorbed over 3.3 per cent H_2SO_4 per gram of colloid	Moisture equivalent	Exchangeable bases per gram of colloid					Exchangeable base capacity per gram of colloid by $BaCl_2$	Degree of saturation	Colloid content of soil determined by H_2O adsorption	Colloid content of soil by mechanical analysis	Colloid extracted from soil	Mols $\dfrac{SiO_2}{Al_2O_3+Fe_2O_3}$
								Ca	Mg	K	Na	Total						
		Inches		*Calories*	*Gram*	*Gram*	*Per cent*	*Milli-equiva-lents*	*Milli-equiva-lents*	*Milli-equiva-lents*	*Milli-equiva-lents*	*Milli-equiva-lents*	*Milli-equiva-lents*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
4	Davidson	0–9	A	7.5	0.045	0.209	67.1	0.064	0.025	0.004	0.010	0.103	0.183	56.3	27.3	30.3	19.0	1.46
		9–36	B_1	5.8	.055	.295	78.8	.032	.020	.002	.008	.062	.126	49.2	64.8	55.3	55.7	1.49
		36–60	B_2	6.0	.058	.319	79.7	.023	.020	.002	.010	.055	.158	34.8	66.5	41.6	42.0	1.42
		84–96	C	6.3	.058	.315	79.4	.025	.020	.004	.026	.075	.156	48.1	29.6	24.2	22.1	1.40
5	Nipe	0–12	1	6.4	.054	.241	58.0	-------	-------	-------	-------	-------	.031	-------	73.9	50.5	-------	.31
		40–60	2	6.8	.053	.240	-------	-------	-------	-------	-------	-------	.020	-------	92.6	56.3	8.1	.17
		100–144	3	5.8	.057	.256	48.8	-------	-------	-------	-------	-------	.021	-------	117.6	50.9	10.0	.42
6	Bauxite	156–214	4	2.9	.018	.065	52.6	-------	-------	-------	-------	-------	.087	-------	32.8	13.3	-------	.84
		250–290	6	1.8	.009	.057	58.1	-------	-------	-------	-------	-------	.199	-------	57.4	35.5	22.0	1.84

The two horizons of the bauxite profile present marked contrasts in the composition of their colloids. The composition of the highly aluminous layer shows a high sesquioxide content characteristic of the laterites, whereas the kaolinitic layer varies but little from the theoretical value of the silica-sesquioxide ratio for kaolinite. Incidentally it may be mentioned that the loss on ignition, in this case practically wholly water, is almost exactly the theoretical value for kaolinite. Property values for the colloids of both horizons are very low, the properties of the kaolinitic layer being far below those usually accompanying soil colloids of corresponding silica-sesquioxide ratio, and more like those of certain pure mineral colloids (*4, 6, 27*).

In view of the unusual character of the colloids of these two horizons it was thought that data regarding their optical properties would be of interest. According to an examination of these two colloids made by W. H. Fry of this bureau, by means of a petrographic microscope, the great mass of the material from the kaolinized horizon is isotropic and has colloidal characteristics. In this isotropic mass faint points of light, between crossed nicols, are plentiful and suggest extremely small crystals. The refractive index of the isotropic aggregates is about 1.56. Occasional faintly doubly refracting aggregates were found. These had an index the same as the isotropic material. Only vague shadows could be observed as interference figures, and these were indeterminate. Very rare crystals, too small for complete study, show the refractive index and approximately the interference figure and axial angle of kaolinite. The material of the aluminous horizon is well aggregated, the aggregates showing a brownish coloration in transmitted light. Practically all the aggregates show a faint double refraction between crossed nicols; but not even a suggestion of an interference figure was obtained. The refractive index is difficult to measure on account of the coloration of the aggregates but is approximately 1.58.

In several respects these materials differ significantly in optical characteristics from those of a large group of colloids described by Hendricks and Fry (*15*). The aluminous horizon was characterized by the absence of any suggestion of an interference figure and by the deep coloration of the colloidal aggregates. The colloid from the kaolinized material was even more strikingly different from that of the commonly obtained soil colloids. It was isotropic, whereas practically all the others studied were anisotropic. It had a lower index of refraction than any of the soil colloids previously reported and lacked the mass optical effect which is usually found.

The exchangeable bases present in the colloids from profiles Nos. 5 and 6 were not determined, since it was shown that the content of total monovalent and divalent bases given in Table 8 are very small and in several cases not more than a trace. The exchangeable base capacity is very small, and judging from the pH values of the soils given in Table 2, the presumption is that the degree of saturation is relatively low. The horizons of profile No. 6, particularly of horizon No. 4, contain a little soluble aluminum sulphate, which is sufficient to account for its low pH value and its high SO_3 content.

COMPARISON OF COLLOIDS FROM DIFFERENT SOIL GROUPS

The reactions typical of the different soil-making processes take place under widely differing climatic conditions and are distinctive in character.   However, the different processes may result in the formation of profiles having horizons whose colloids possess considerable similarity in chemical character.

In order to facilitate comparison of the colloids of the different classes their major constituents have been recalculated on the basis $SiO_2 + Al_2O_3 + Fe_2O_3 = 100$.   These values, together with the silica-sesquioxide ratios from previous tables, are given in Table 10.

TABLE 10.—*Chemical composition of soil colloids calculated on the basis $SiO_2 + Al_2O_3 + Fe_2O_3 = 100$*

Profile No.	Soil series	Depth	Horizon	SiO₂	Al₂O₃	Fe₂O₃	Mols SiO₂ / Al₂O₃ Fe₂O₃
		Inches		*Per cent*	*Per cent*	*Per cent*	
		0–5	1	62.09	27.09	10.82	3.10
		10–20	2	62.19	27.42	10.39	3.09
1	Amarillo	30–40	3	62.43	27.28	10.29	3.13
		54–64	4	61.35	28.84	9.81	2.97
		70–76	5	62.20	28.56	9.24	3.06
		96–100	6	62.97	27.57	9.46	3.18
		0–3	A₀	66.44	23.89	9.67	3.76
		3–8	A₂	68.52	24.72	6.75	4.01
2	Superior	12–30	B	45.01	35.81	19.18	1.59
		30–40	C	55.14	28.77	16.09	2.40
		0–6	A₀	52.35	29.64	18.01	2.16
		6–11	A₂	59.80	31.56	8.64	2.74
3	Beckett	11–13	B₁	28.03	25.16	46.82	.86
		13–24	B₂	39.46	36•71	23.83	1.28
		24–36	C	46.71	37.50	15.79	1.67
		0–9	A	43.62	40.67	15.71	1.46
		9–36	B₁	43.63	37.43	18.94	1.49
4	Davidson	36–60	B₂	41.41	34.46	24.13	1.42
		60+	C	41.44	34.02	23.54	1.40
		0–12	1	11.51	17.89	70.60	.31
5	Nipe	40–60	2	6.64	13.72	79.64	.17
		100–144	3	15.28	21.26	63.46	.42
		156–214	4	31.91	57.07	10.12	.84
6	Bauxite	250–290	6	51.62	46.23	2.15	1.84

So far as the major constituents alone are concerned the podsol colloids embody in a single profile a range of chemical variation comparable with the colloids from the widest extremes of climate.   In the A_1 horizons they are as high in silica and have as high silica-sesquioxide ratios as colloids from pedocal profiles formed under low rainfall.   In the B horizons they have the silica-sesquioxide relationships characteristic of hot humid conditions where lateritization is far advanced.   The profiles as a whole, however, show wide differences from those of either the pedocal or lateritic soils.   Under these circumstances variations in some of the minor constituents, such as organic matter and monovalent and divalent bases, indicate significant differences between the groups.   Furthermore, there is some evidence that even the iron present may show differences not revealed by a gross analysis of major constituents.   Qualitative observations indicate a marked difference in the character of the iron compounds of the B horizons of the podsols as compared with either the laterites or the red colloids of the pedocal profile, the iron in the podsols being much more soluble in 0.05 N HCl.   The podsol colloids of the B horizons have monovalent and divalent bases somewhat in excess

of those of lateritic colloids of similar major constituents. Furthermore, the podsol colloids of the A horizons with major constituents similar to those of the pedocals have somewhat similar base contents but are characterized by property values much lower than those of colloids from the more arid regions. This is probably to be accounted for by the presence of free silica in the colloid.

The data given in Tables 6 and 9 show, in some cases, much wider variations in the adsorption of water vapor over 3.3 per cent sulphuric acid than the values shown for the colloids of most agricultural soils. There are some indications that in certain of these unusual soils, samples of the colloid extracted may be less representative of the whole amount present and that greater alteration of adsorptive power may take place on extraction than is usually the case (13). This determination when used as a basis for estimating the colloid content of soils would then in these unusual cases, whether of large organic content or of very low silica-sesquioxide ratio, be expected to show somewhat less accurate results than are usually obtained by this method. Therefore, the results in Tables 4, 6, and 9, comparing the colloid contents by two methods, show in some cases discrepancies of the type that would be expected. These discrepancies would, of course, be in some cases, minimized and in others increased if an arbitrary adsorption value of 30 per cent were assumed for the colloid in each case.

Values for colloid content indicated by the other methods dependent on property values of the colloids would also be expected to show less than the ordinary degree of accuracy.

pH VALUES OF ELECTRODIALYZED COLLOIDS

The pH values of the different isolated colloids are not included in the data presented in the foregoing tables on account of the influence which varying quantities of deflocculant may have had on this determination. There is, however, some indication that the pH values of the colloids after electrodialysis may be of significance.

It is well known that electrodialyzed soils are usually much more acid than the most extreme samples of naturally occurring agricultural soils. There is also an indication that the pH values of different electrodialyzed soils may show considerable variation (2, 8, 19). It may be assumed that the acid character of the electrodialyzed soils resides primarily in the colloidal material and that the intensity of the acidity developed may, like many other properties, vary with the chemical character of the colloids.

Preliminary study of a few of the colloids used in the present investigation showed significant differences in the pH values of certain ones having varying silica-sesquioxide ratios. It seemed desirable therefore to investigate the remainder of the group. As the work progressed it became evident that the determination was greatly influenced by several factors, important among which are the colloid-water ratio and presumably the state of dispersion, although no specific data were obtained regarding the magnitude of the latter. Duplicate results of pH determinations may be obtained readily when samples of a colloid in a similar physical condition are electrodialyzed and the same proportions of colloid and water used. But if the condition of the material varies, there is indication that considerable

differences in pH values may be expected. Each of the colloids dialyzed in these studies had been air-dried and ground previous to dialysis. As the work progressed it appeared probable that somewhat lower pH values might, in some cases at least, have been obtained if freshly dispersed colloid had been placed in the dialyzer instead of that which had been air-dried. Colloids of course flocculated in the dialyzer and settled, leaving ordinarily a clear supernatant liquid. It was possible to obtain from the bottom of the chamber any concentration of suspension desired. An attempt was made in each case to use for pH determinations approximately the maximum concentration in which an electrometric determination could be properly made in an electrode vessel of the bubbling type. The ratio of colloid to water was in most cases approximately 1 to 2 or 3.

The pH values of the various electrodialyzed colloids are given in Table 11. Included in this table are the pH values of the freshly dialyzed colloid, the same colloids after being air-dried for several weeks and subsequently submerged in water for three days, also the pH values of the supernatant liquid from the colloid in the dialyzer when it was obtainable clear or nearly so.

The data in Table 11 indicate a tendency toward a direct relationship between hydrogen-ion concentration and silica-sesquioxide ratio. This relationship is, however, not a close one, and about all that can be said from the data at hand is that the hydrogen-saturated laterites have, as a rule, higher pH values than those of colloids of higher silica-sesquioxide ratio. If methods were available which would obviate the variations due to differences in dispersion and other more or less intangible factors, the relationship might appear much closer. As a rule, the colloids of low silica-sesquioxide ratio show a more marked tendency toward flocculation when hydrogen saturated than do those of higher ratio, and this may be responsible for part of the differences in pH value.

TABLE 11.—*Hydrogen-ion concentration of electrodialyzed soil colloids*

Soil series	Horizon	Depth	Minimum pH of fresh suspension	pH after drying and 3 days' subsequent submersion	pH of clear liquid above colloid	Mols $\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$
		Inches				
Amarillo	1	0–5	3.18	3.24	6.87	3.10
	2	10–20	2.89	3.44	4.95	3.09
	3	30–40	3.01	3.31	6.58	3.13
	4	54–64	2.45	3.20		2.97
	5	70–75	3.08	3.75		3.06
	6	96–100	3.08	3.50		3.18
Superior	A₀	0–3	2.73		6.89	3.76
	A₁	3–8	3.21		4.73	4.01
	B	12–30	4.24			1.50
	C	30–40	4.15	4.78	5.91	2.40
Beckett	A₀	0–6	3.02		5.81	2.16
	A₁	6–11	2.15	3.04	6.24	.86
	B₂	13–24		4.78	4.60	1.28
Davidson	A	0–9	3.06	4.85		1.46
	B₁	9–36	3.31	3.58		1.40
	B₂	36–60	3.97	4.02		1.42
	C	60+		4.21		1.40
Nipe	1	0–12	5.08		6.12	.31
	3	100–144	5.27		6.07	.42
Bauxite	4	156–214	4.36		6.45	.84
Kaolinized syenite	6	250–290	4.29			1.84

Marked differences have been observed by Bradfield (*8*) in the pH values of electrodialyzed colloids and clear solutions from which the colloidal materials have settled.   It is evident that the hydrogen ions closely associated with the micellæ are in many cases responsible for most of the acidity shown by such materials.   Taking the colloid from horizon 1 of the Amarillo profile as an illustration, the supernatant liquid shows only negligible deviation from theoretical neutrality, whereas a suspension of the colloid shows a pH value corresponding to about 0.0007 normal solution of completely ionized acid.   In view of the enormous influence of what may be presumed to be surface hydrogen ions it may be assumed that surface contact of a colloid micella upon the hydrogen electrode is an important factor in the pH determination of such materials.

The colloids which were air-dried and remained in this condition for several weeks before being submerged and the pH values redetermined, show in most cases, higher pH values than the fresh materials.   Although a part of the apparent comeback may have been due to poorer dispersion after drying, nevertheless, some real change probably took place.   The work of Alben (*2*) with soils showed about the same differences in pH value when electrodialyzed soils were kept submerged and when allowed to dry out.   The comeback shown by the electrodialyzed colloids is probably indicative of a tendency on the part of the so-called nonexchangeable bases to undergo rearrangement within the particle in such manner that a part of such bases are capable of ionizing in the surface layer.   In other words, this change is indicative of a transformation of some of the nonexchangeable base into exchangeable form.   This explanation accords with unpublished data presented by Kelley (*20*).

SUMMARY

The results of the influence of each of three major soil-making processes on the character of the colloidal materials developed in a soil profile were studied.   The processes include calcification, podsolization, and lateritization.   Each profile studied is representative of the dominating influence of a single one of these processes operative to the extent of developing a typical profile of its kind.

The chemical composition of each of the colloids and the various properties which serve to characterize these materials were studied. These properties include heat of wetting, adsorption of water vapor over 30 per cent sulphuric acid and over 3.3 per cent sulphuric acid, moisture equivalent, content of exchangeable monovalent and divalent bases, and base-exchange capacity.

On the basis of the data presented the calcification process leads to uniformity of colloidal material so far as major chemical constituents are concerned.   The ratio of silica to sesquioxides is relatively high as are also most of the property values.   Colloidal calcium carbonate is present in the lower horizons and this material appears to possess relatively low property values.

The podsolization process leads to the formation of profiles containing colloidal materials of widely varying character in the different horizons.   Silica-sesquioxide ratios of the A_0 and A_1 horizons are high, those of the B horizons are relatively low, and those of the C somewhat higher than those of the B.   Property values of the A_1

and B colloids are anomalous, those of the A_1 being much lower and those of the B horizon colloids much higher than usually accompany such silica-sesquioxide ratios. Organic matter is shown to play an important part in the properties of these colloids.

The lateritization process leads to the development of colloids whose ratio of silica to sesquioxides is low and whose property values are low. The kaolinized horizon has low property values comparable to those of mineral powders rather than to ordinary soil material.

The hydrogen-ion concentration of electrodialyzed colloids varies widely. These variations show no close relationship to chemical composition. However, there is some tendency toward a direct relationship between hydrogen-ion and silica-sesquioxide ratio, the pH values of the laterites being much higher than those of colloids with high silica-sesquioxide ratio. Long standing of the colloids after electrodialysis brought about an increase in pH values, suggesting that a part of the nonexchangeable bases of the colloid particles may have become exchangeable, thus replacing some of the hydrogen-ions in the surface layers.

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