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THE COMPOSITION OF SOIL COLLOIDS IN RELATION TO SOIL CLASSIFICATION

BY HORACE G. BYERS AND M. S. ANDERSON

Introduction

For a period of approximately fifteen years investigators in the Bureau of Chemistry and Soils have been engaged in the accumulation of scientific data concerned with colloid material of the soil. During this period a large volume of accurate information has been secured which has been published in the form of bulletins and journal articles. So far as the Bureau publications are concerned, but little has appeared concerning theoretical aspects of the composition of the colloid. They have concerned themselves, for the most part, with methods of isolation and estimation, and determination of general physical and chemical characteristics.

Meanwhile it is recognized that two more or less clearly defined ideas concerning the character of the colloidal complex have been developed. The one which for some years was dominant, and which, without serious error, may be attributed to van Bemmelen and Stremme, regarded the soil complex as essentially a mixture of three oxides, those of silicon, aluminium and iron. The water and bases of the complex were regarded as held by 'surface' reactions which are not described in terms of the ordinary laws of chemical behavior. The other view, which, of course, is really much older, but submerged for a time by the flood of physico-chemical research, has reappeared, and, indeed, has again become orthodox, though as yet not fully formulated. This view regards the colloid complex as essentially a group of acids, organic and inorganic, which are both weak and unstable, as well as insoluble and essentially amorphous. The salts of these acids, which are the colloid, behave as described by the ordinary laws of chemistry modified by this unusual combination of properties. The essential complex is also in special cases modified by the possible presence of undecomposed minerals and of the *ultimate* products of their hydrolysis. The variants of this view are almost as numerous as the number of contributors to it. In the near future the Bureau of Chemistry and Soils expects to present a discussion of its accumulated data bearing upon this question. Some comments only will appear in the present paper.

In recent years, largely due to the activities of, or stimulated by, the Soil Survey, under the direction of Dr. C. F. Marbut, and based initially upon the investigations of Russian soil workers, there has been developed a system of soil classification dependent upon the properties of the soil profile. This classification takes into consideration, in addition to the dynamic factor of soil development, the parts played also by the parent material in the genesis of the soil. It is the purpose of the present discussion to consider some of our recently accumulated data in their relation to this system of classification and to the composition of the acid complex of the soil.

TABLE I

TABULAR ARRANGEMENTS OF SOIL GROUPS INTO CATEGORIES

Category VII   1. Pedalfers   2. Pedocals

Category VI   1. Podsolic soils   3. Pedocals of Temperate Zone
              2. Lateritic soils   4. Pedocals of Tropical Zone

Category V   Sub-groups of Group   1. Chernozem
           10 in Category IV   2. Chestnut colored
                                3. Brown
                                4. Gray
                                5. Sub-groups of groups 9, 11 and 12 of Category IV, none of which have yet received distinctive names

Category IV   1. Tundra   9. Northern Temperate Pedocals
              2. Podsols   10. Mid-latitude Temperate Pedocals
              3. Gray-brown podsolic   11. Southern Temperate Pedocals
                soils   12. The various still unknown groups
              4. Red soils   of Tropical Pedocals
              5. Yellow soils
              6. Prairie soils
              7. Laterites
              8. Ferruginous laterites

Category III   1. Soils with perfectly   3. Soils with perfectly
                   developed profiles   developed profiles
              2. Soils with imperfectly   4. Soils with imperfectly
                   developed profiles   developed profiles

Category II   1. Soil Series Groups   2. Soil Series Groups
                   (a very great number)   (a very great number)

Category I   1. Soil units based on   Soil units based on
                   texture of surface   texture of surface
                   horizon   horizon

    Without making a critical historical résumé of the development, from a beginning made by Milton Whitney about forty years ago, of the system of soil classification used in the United States, it may be stated that, while it is the result of a field study of the characteristics of the soil, for many years it was largely confined to a study of the surface, and, to a lesser degree, of

the subsoil. The views of Ramann[1], based largely upon the data of Cushman[2,3] and co-workers in the Bureau of Chemistry and the Office of Public Roads that the weathering of the silicates is "really a result of the hydrolytic action of water," has been accepted, and the work has been greatly influenced by the publication in 1914 of the work of the Russian soil scientists by Glinka.[4] The work of the Soil Survey since 1890, influenced by these results and others, has resulted in the system outlined by Marbut,[5] to be published in the near future. In this system, which was developed through a study of the soils themselves, the influence of environmental factors in producing, and in furnishing explanation of the observed results has been recognized. These factors are chiefly the vegetative conditions which are at the same time determining factors of, and a result of, soil and climate; the climatic conditions, especially of temperature and rainfall; the duration of the soil forming processes; the relation of the terrain to the drainage and to the water table, and the material producing the soil. In this classification, given in Table I, the whole soil profile is considered, Horizon A and its subdivisions, with Horizon B and its subdivisions together constituting what may be considered the solum, or true soil, while the disintegrated parent material is called Horizon C. It is of very considerable interest to discover whether this scheme of classification is reflected by the composition of the soil colloid.

Data and Discussion

Previous to 1924 only a very few chemical analyses of colloid material were available. These were, for the most part, either partial analyses of fine soil fractions or of clays, or were not associated with sufficient field information to permit of any general conclusions.

In 1924 a bulletin by Robinson and Holmes[6] gave the analyses of 44 colloids derived from 19 soil series. On the basis of these analyses the authors drew some very significant conclusions regarding not only the constitution of the soil colloid itself, but also that the molecular ratio of silica to the sesquioxides in a colloid is characteristic of the soil series from which it is derived. They were led to conclude that rainfall is a very important factor in determining colloid composition in that silica is more readily removed by leaching than are the sesquioxides, and high rainfall tends towards the decrease of the ratio. Also since calcium and sodium disappear from soils more readily through leaching than do sesquioxides, therefore the molecular relation of the sum of these bases to the sum of the sesquioxides indicates, by its magnitude, the extent to which leaching has occurred. It follows that, in a general way, these ratios are parallel. In this bulletin, also, the authors call attention

[1] Ramann: "Bodenkunde" (1911).

[2] A. S. Cushman: The Effect of Water on Rock Powders. U.S.D.A. Bureau of Chemistry, Bulletin 92 (1905).

[3] A. S. Cushman and P. Hubbard: The Decomposition of Feldspars. U.S.D.A. Office of Public Roads, Bulletin 28 (1907).

[4] "Die Typen der Bodenbildung" (1914).

[5] "The Soils of the United States" (1931).

[6] "The Chemical Composition of Soil Colloids," U.S.D.A. Bulletin No. 1311 (1924).

to the relationship between the quantities of silica, alumina and iron oxide required to form the compounds kaolinite and nontronite on the assumption that these exist in the colloid and have the general formula $2H_2O: M_2O_3: 2SO_2$.

Many other investigators have discussed the relation of silica to sesquioxides and of silica to alumina in their relation to the different portions of the soil profile, both in the soil itself and in the colloid fraction. Recently, G. W. Robinson[1] has called attention to variations of the magnitude of the silica-sesquioxide ratio as a result of profile development in Wales. He finds a general tendency toward increase of sesquioxides in the B horizon as compared with the surface soil. These results are in accord with those of Tamm[2] in Sweden, and, indeed, with all investigations of northern humid soils.

The extensive data now available for American soils, most of which have found publication in recent bulletins,[3] render possible a general comparison between the soils and the soil-making processes, and for this purpose the data are presented in full in Tables II and III. In these tables the analytical results have been recalculated in order to better bring out the points under discussion.

In Table II are given the data for soils from both of the main sub-divisions of soils, the Pedocals and the Pedalfers (Marbut's Category 7). The pedocals are represented by the Amarillo silt loam from Texas (Marbut's Category 4) and the Barnes silt loam from South Dakota (Marbut's Category 5). The Pedalfers are represented by three podsols, the Superior fine sandy loam from Wisconsin, the Beckett loam from Massachusetts, and the Emmet fine sandy loam from Michigan. The gray-brown podsolic soils are represented by the Miami silt loam, Chester loams and sandy loams, and Leonardtown silt loams, the mean values of the data for which are given in Table II and the detailed data in Table III. The red soils are represented by the Davidson clay loam from North Carolina, and by the mean values of the Cecil clay loams and sandy clays from Virginia, North Carolina and Georgia, given in Table III. The laterites are represented by the Nipe clay from Cuba, which is a ferruginous laterite. So far as we know, there are no modern truly laterite soils in the United States. The prairie soils are represented by the Marshall silt loam from Nebraska and the Shelby silt loam from Missouri.

In the following discussion the soil making process, so far as its chemical relations are concerned, is considered as essentially one of progressive hydrolysis of the soil minerals. Out of this material the soil development processes, such as translocation or elimination of the products of hydrolytic action and other processes, produce the soil. Translocation of material involves true solution or colloidal suspension, or both. It is recognized, of course, that the hydrolytic process is profoundly influenced by the "catalytic" effect of the presence of carbonic and organic acids and its rate is also a function of the temperature and of the character of the material being acted upon. It is

[1] J. Agr. Sci., 20, 618-39 (1930).

[2] Meddel. Statens Skogsförsöksant (Sweden) 17, 49-300 (1920).

[3] Robinson and Holmes: Loc. cit; Holmes: J. Agr. Research, 36, 459-70 (1930); Holmes and Edington: U.S.D.A. Tech. Bull., 229 (1930); Denison: J. Agr. Research, 40, 469-83 (1930); Anderson and Byers: U.S.D.A. Tech. Bull., 229 (1931).

TABLE II

Chemical Constituents of Colloids from Soils characteristic of Various Soil Groups

Location of Profile	Horizon	Depth	Chemical composition calculated on the basis $SiO_2+Al_2O_3+Fe_2O_3=100$			Molecular ratios				Monovalent and divalent bases calculated as milliequivalents per 100 grams					Total base exchange capacity by $BaCl_2$
		inches	SiO_2 per cent	Al_2O_3 per cent	Fe_2O_3 per cent	$\frac{SiO_2}{Al_2O_3+Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	Ca[1] milli-equiv-alents	Mg milli-equiv-alents	K milli-equiv-alents	Na milli-equiv-alents	Total milli-equiv-alents	milli-equiv-alents
Colloids of the Pedocal Group															
Amarillo, Tex.	1	0–5	62.09	27.09	10.82	3.10	3.88	15.19	.255	52.8	103.2	56.9	1.9	220.8	56.6
	2	10–20	62.19	27.42	10.39	3.09	3.85	15.84	.243	56.7	132.0	53.9	0.3	242.9	62.8
	3	30–40	62.43	27.28	10.29	3.13	3.87	16.06	.241	65.4	138.9	53.1	1.9	259.3	63.4
	4	54–64	61.35	28.84	9.81	2.97	3.60	16.57	.217	61.7	140.4	51.4	3.2	256.7	69.2
	5	70–75	62.20	28.56	9.24	3.06	3.68	17.79	.207	75.0	125.5	38.9	1.9	241.3	65.6
	6	96–100	62.97	27.57	9.46	3.18	3.86	17.66	.219	56.4	142.4	48.0	0.3	247.1	70.0
Barnes, S. D.	A₀	0–2½	62.65	23.47	13.88	3.30	4.53	11.93	.379	59.2	47.6	44.8	58.1	209.7	—
	B₂	14–48	60.89	23.85	15.26	3.09	4.32	10.57	.408	46.7	63.0	41.0	45.5	196.2	—
	C₂	60–78	64.00	21.48	14.52	3.55	5.05	10.31	.432	—	—	—	—	—	—
Colloids of Podsol Soils															
Superior, Wis.	A₀	0–3	66.44	23.89	9.67	3.76	4.71	18.12	.260	62.1	52.1	16.8	8.4	139.4	78.1
	A₁	3–8	68.52	24.72	6.75	4.01	4.70	26.88	.175	36.1	62.0	45.4	11.0	154.5	56.3
	B	12–30	45.01	35.81	19.18	1.59	2.13	6.20	.343	23.6	84.8	29.1	4.8	142.3	44.0
	C	30–40	55.14	28.77	16.09	2.40	3.24	9.08	.357	21.8	169.2	26.1	1.9	219.0	39.9
Beckett, Mass.	A₀	0–6	52.35	29.64	18.01	2.16	2.99	7.68	.389	23.2	15.4	10.4	8.1	57.1	78.9
	A₁	6–11	59.80	31.56	8.64	2.74	3.22	18.30	.175	14.3	51.1	53.3	7.7	126.4	51.1
	B₁	11–13	28.03	25.15	46.82	0.86	1.88	1.58	1.189	11.4	32.2	17.6	3.9	65.1	—
	B₂	13–24	39.46	36.71	23.83	1.28	1.83	4.39	.416	5.7	58.5	42.0	9.0	115.2	53.7
	C	24–36	46.71	37.50	15.79	1.67	2.11	7.83	.270	6.1	104.2	87.0	8.1	205.1	18.9
Emmet, Mich.	A₁	1–4	61.13	29.26	9.61	2.94	3.55	16.88	.211	19.2	8.9	55.4	23.9	107.4	—
	B₃	24–33	55.33	27.35	17.32	2.45	3.41	8.46	.404	66.0	81.8	56.1	23.2	227.1	—
	C₂	48–60	62.50	19.92	17.58	3.40	5.33	9.41	.566	—	—	—	—	—	—
Colloids of Gray-brown Podsolic Soils															
Miami Mean values of 9 profiles	A₁		58.90	30.01	11.08	2.69	3.33	14.18	.237	27.0	103.5	56.6	7.6	194.7	32.7
	B		56.76	29.70	13.54	2.50	3.25	11.13	.291	26.3	130.0	72.6	4.8	233.7	38.7
	C		57.85	29.19	12.97	2.61	3.36	11.72	.284	111.8	156.7	94.9	7.8	350.5	36.3
Leonardtown Mean values of 6 profiles	A		51.50	34.10	14.40	2.01	2.50	9.62	.268	14.8	44.1	30.2	11.6	100.8	19.7
	B		51.19	32.76	16.05	2.01	2.62	8.29	.317	10.4	42.5	26.8	10.6	90.4	22.7

[1] Where analyses show carbonates to be present an equivalent amount of Ca is deducted. In some cases, however, analyses do not include carbonate, which may be present.

TABLE II (Continued)

Chemical Constituents of Colloids from Soils characteristic of Various Soil Groups

Location of Profile	Horizon	Depth inches	Chemical composition calculated on the basis $SiO_2+Al_2O_3+Fe_2O_3=100$			Molecular ratios				Monovalent and divalent bases calculated as milliequivalents per 100 grams					Total base exchange capacity by $BaCl_2$ milli-equivalents
			SiO_2 per cent	Al_2O_3 per cent	Fe_2O_3 per cent	$\frac{SiO_2}{Al_2O_3+Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	Ca^1 milli-equiv-alents	Mg milli-equiv-alents	K milli-equiv-alents	Na milli-equiv-alents	Total milli-equiv-alents	
Colloids of Gray-brown Podsolic Soils, Continued															
Chester, Mean values of 8 profiles	A		44.65	38.82	16.53	1.54	1.96	7.51	.273	20.5	77.5	20.9	3.5	122.4	25.6
	B		46.94	35.39	17.42	1.69	2.26	7.36	.323	13.6	69.9	24.2	3.0	110.6	21.9
	C		45.53	38.69	15.77	1.59	2.00	9.06	.271	11.8	46.8	19.0	3.0	80.6	15.3
Colloids of Red Soils															
Davidson, N. C.	A	0–9	43.62	40.67	15.71	1.46	1.82	7.36	.247	20.7	45.6	10.6	1.0	87.9	18.3
	B₁	9–36	43.63	37.43	18.94	1.49	1.97	6.10	.323	20.0	20.3	7.9	trace	48.2	12.6
	B₂	36–60	41.41	34.46	24.13	1.42	2.03	4.54	.448	12.5	17.9	3.8	trace	34.2	15.8
	C	60+	41.44	34.92	23.64	1.40	2.01	4.64	.434	17.8	3.0	3.6	trace	24.4	15.6
Cecil, Mean values for 8 profiles	A		44.41	43.18	12.42	1.45	1.64	9.75	.184	7.5	22.0	15.0	1.6	45.3	11.6
	B		42.02	42.81	15.17	1.38	1.57	7.47	.228	6.0	15.1	8.6	1.9	34.1	8.1
	C		42.62	41.91	15.48	1.40	1.63	7.41	.238	4.8	14.5	10.3	2.1	31.7	7.7
Colloids of Laterite Soils															
Nipe, Cuba	1	0–12	11.51	17.89	70.60	0.31	1.09	0.43	2.525	8.2	2.5	trace	trace	10.7	3.1
	2	40–60	6.64	13.72	79.64	0.17	0.81	0.22	3.723	trace	3.5	1.5	0.6	5.6	2.0
	3	100–144	15.28	21.26	63.46	0.42	1.22	0.64	1.915	trace	10.4	3.4	1.0	14.8	2.1
Colloids of Prairie Soils															
Marshall	1	0–14	59.97	28.36	11.67	2.82	3.58	13.14	.263	42.5	99.7	47.3	6.8	196.3	—
	2	14–36	60.07	27.43	12.50	2.87	3.72	12.59	.292	48.5	80.3	44.0	4.8	177.6	—
Shelby	1	0–7	58.35	29.90	11.75	2.64	3.31	12.40	.252	47.1	92.7	25.5	7.1	172.4	—
	2	8–12	57.99	29.81	12.20	2.61	3.30	11.42	.262	46.0	92.8	24.0	6.8	169.6	—
	3	12–20	57.83	29.80	12.36	2.60	3.28	11.18	.265	48.9	100.0	26.8	9.3	175.9	—
	4	20–24	57.56	29.00	13.35	2.60	3.36	10.80	.294	58.2	107.7	28.0	12.3	206.2	—
	5	24–48	58.41	27.75	13.84	2.71	3.57	13.61	.319	77.4	102.7	34.6	14.2	228.9	—
	6	48–60	57.98	27.79	14.23	2.67	3.54	12.72	.328	83.8	102.7	35.2	13.2	234.9	—

¹ Where analyses show carbonates to be present an equivalent amount of Ca is deducted. In some cases, however, analyses do not include carbonate, which may be present.

TABLE III

Chemical Constituents of Colloids characteristic of Various Soil Series

Location of Profile	Horizon	Depth	Colloids of the Miami Series							Monovalent and divalent basis calculated as milliequivalents per 100 grams					Total base exchange capacity by BaCl₂
			Chemical composition calculated on the basis SiO₂+Al₂O₃+Fe₂O₃=100			Molecular ratios									
			SiO₂	Al₂O₃	Fe₂O₃	$\frac{SiO_2}{Al_2O_3+Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	Ca	Mg	K	Na	Total	
		inches	per cent	per cent	per cent					milli-equiv-alents	milli-equiv-alents	milli-equiv-alents	milli-equiv-alents	milli-equiv-alents	milli-equiv-alents
Eaton Co., Mich.	A	6–10	58.48	30.01	11.51	2.65	3.29	13.46	.245	18.9	121.5	57.5	6.8	204.7	31.7
	B	18–30	57.57	29.04	13.39	2.59	3.36	11.39	.295	28.9	153.3	76.8	8.1	267.1	37.5
	C	34–40	58.29	28.12	13.59	2.68	3.51	11.36	.309	44.6	169.6	85.4	11.0	310.6	42.6
Washtenaw Co., Mich.	A	0–8	59.45	29.76	10.79	2.75	3.39	14.58	.233	33.9	105.7	73.9	11.3	224.8	31.7
	B	8–30	57.29	29.89	12.82	2.55	3.25	11.83	.275	33.2	136.9	97.2	8.4	275.7	33.8
	C	54+	58.57	29.08	12.35	2.69	3.41	12.55	.271	183.7	161.2	100.4	10.6	455.9	23.7
Branch Co., Mich.	A	2–8	60.47	29.84	9.69	2.84	3.43	16.52	.208	7.1	107.6	58.2	8.4	181.3	22.9
	B	9–36	56.59	30.48	12.93	2.48	3.15	11.61	.271	23.5	136.4	90.9	3.2	254.0	33.7
	C	40–60	58.15	29.75	12.10	2.62	3.31	12.72	.260	61.7	155.7	100.4	4.8	322.6	34.3
Miami Co., Ind.	A	4–10	58.37	29.51	12.11	2.66	3.35	12.77	.263	32.8	109.6	55.4	6.8	204.6	29.3
	B	12–20	56.81	29.08	14.11	2.52	3.31	10.66	.310	31.4	142.4	73.3	5.8	252.9	42.5
	A	6–10	59.30	28.84	11.86	2.75	3.49	13.25	.263	34.3	97.7	55.0	4.2	191.2	31.3
	B	15–20	57.01	29.81	13.18	2.53	3.24	11.45	.283	31.4	123.0	60.7	4.5	219.6	40.3
	C	40–50	57.35	29.57	13.08	2.55	3.28	11.62	.282	133.1	154.3	89.2	7.7	384.3	34.2
Blackford Co., Ind.	A	4–7	59.89	30.29	9.82	2.78	3.30	15.92	.207	28.9	120.5	64.3	8.1	221.8	36.8
	B	11–18	56.44	30.37	13.19	2.48	3.15	11.33	.278	27.5	129.0	83.9	4.8	245.2	39.1
	C	38–42	58.14	29.29	12.57	2.64	3.36	11.33	.274	81.0	142.9	102.5	6.5	332.9	32.8
Grant Co., Ind.	A	3–9	61.01	28.85	10.14	2.92	3.58	15.94	.225	32.1	107.1	51.0	6.5	196.7	32.9
	B	10–26	56.58	29.60	13.82	2.37	3.23	10.84	.298	19.3	126.0	69.4	3.2	217.9	37.9
	C	32–42	57.92	28.93	13.15	2.57	3.39	11.66	.290	52.1	147.8	101.1	9.4	310.4	35.2
Hancock Co., Ind.	A	2–12	55.89	32.47	11.64	2.39	2.91	12.71	.229	32.8	58.0	52.7	11.0	154.5	36.5
	B	16–32	55.83	29.54	14.63	2.43	3.30	10.10	.317	25.0	119.1	57.5	2.3	203.9	40.5
	C	36+	56.90	29.28	13.82	2.53	3.30	10.89	.303	53.5	153.3	90.9	5.2	302.9	36.4

TABLE III (Continued)

Chemical Constituents of Colloids characteristic of Various Soil Series

Location of Profile	Horizon	Depth	Chemical composition calculated on the basis SiO₂+Al₂O₃+Fe₂O₃=100			Molecular ratios				Monovalent and divalent basis calculated as milliequivalents per 100 grams					Total base exchange capacity by BaCl₂
		inches	SiO₂ per cent	Al₂O₃ per cent	Fe₂O₃ per cent	$\frac{SiO_2}{Al_2O_3+Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	Ca milli-equiv-alents	Mg milli-equiv-alents	K milli-equiv-alents	Na milli-equiv-alents	Total milli-equiv-alents	milli-equiv-alents
Colloids of the Miami Series, Continued															
Rush Co., Ind.	A	5–14	57.33	30.49	12.18	2.50	3.19	12.45	.256	22.1	104.2	41.8	5.2	173.3	41.1
	B	14–18	56.75	29.48	13.77	2.51	3.27	10.92	.299	16.8	103.7	43.7	3.2	167.4	43.3
	C	60.64	57.45	29.48	13.07	2.57	3.30	11.64	.283	285.4	168.7	89.2	6.8	550.1	51.2
Mean Values	A		58.90	30.01	11.08	2.69	3.33	14.18	.237	27.0	103.5	56.6	7.6	194.7	32.7
	B		56.76	29.70	13.54	2.50	3.25	11.13	.291	26.3	130.0	72.6	4.8	233.7	38.7
	C		57.85	29.19	12.97	2.61	3.36	11.72	.284	111.8	156.7	94.9	7.8	350.5	36.3
Colloids of the Leonardtown Soil Series															
Prince Georges Co., Md.	A	0–7	51.51	33.24	15.25	2.03	2.62	8.95	.293	20.4	52.5	31.0	12.9	116.8	—
	B	7–17	50.86	33.04	16.10	1.99	2.61	8.36	.312	14.3	52.5	27.8	11.6	106.2	—
Prince Georges Co., Md.	A	0–12	49.09	37.26	13.65	1.80	2.21	9.81	.226	8.2	43.7	31.9	13.9	96.7	23.0
	B	12–18	52.14	33.10	14.76	2.07	2.64	9.35	.286	7.5	43.7	28.0	7.7	86.9	23.3
Charles Co., Md.	A	0–7	51.97	33.33	14.70	2.05	2.27	9.36	.282	16.8	44.1	28.5	13.9	103.3	21.0
	B	7–14	51.61	32.58	15.81	2.05	2.69	8.64	.311	12.9	33.7	22.3	11.9	80.8	21.5
	A	0–7	51.28	33.83	14.89	2.03	2.57	9.11	.281	16.1	38.7	28.7	17.4	100.9	18.5
	B	7–14	50.72	33.12	16.16	1.98	2.53	7.24	.305	8.6	37.7	22.1	16.8	85.2	21.5
Prince Georges Co., Md.	A	1–8	53.56	33.35	13.09	2.15	2.72	11.30	.251	11.8	37.7	30.2	3.9	83.6	15.1
	B	8–18	51.41	31.73	16.86	2.05	2.75	8.08	.340	5.0	45.6	30.2	8.4	89.2	23.8
	A	1–8	51.57	33.60	14.83	2.02	2.60	9.20	.283	15.4	48.1	32.1	7.7	103.3	21.1
	B	8–18	50.41	33.00	16.59	1.97	2.59	8.05	.322	14.3	41.7	30.4	7.4	93.8	23.3
Mean Values	A		51.50	34.10	14.40	2.01	2.50	9.62	.268	14.8	44.1	30.2	11.6	100.8	19.7
	B		51.19	32.76	16.05	2.02	2.62	8.29	.317	10.4	42.5	26.8	10.6	90.4	22.7

TABLE III (Continued)

Chemical Constituents of Colloids characteristic of Various Soil Series

Location of Profile	Horizon	Depth inches	Chemical composition calculated on the basis $SiO_2+Al_2O_3+Fe_2O_3=100$			Molecular ratios				Monovalent and divalent basis calculated as milliequivalents per 100 grams					Total base exchange capacity by $BaCl_2$ milli-equivalents
			SiO_2 per cent	Al_2O_3 per cent	Fe_2O_3 per cent	$\frac{SiO_2}{Al_2O_3+Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	Ca milli-equiv-alents	Mg milli-equiv-alents	K milli-equiv-alents	Na milli-equiv-alents	Total milli-equiv-alents	
Colloids of the Chester Series															
Chester Co., Pa.	A	0–9	42.57	37.10	20.33	1.44	1.94	5.52	.352	30.7	140.9	20.0	5.5	197.1	29.9
	B	9–28	40.56	33.84	25.60	1.38	2.03	4.20	.483	12.1	111.6	20.2	1.9	145.8	18.4
	C	40+	43.13	33.46	23.41	1.51	2.19	4.86	.450	14.3	84.3	24.0	2.3	124.9	18.2
Cecil Co., Md.	A	1–8	42.47	39.74	17.79	1.41	1.81	6.32	.287	3.2	120.5	8.7	0.3	132.7	27.7
	B	8–30	47.88	33.96	18.16	1.78	2.39	6.97	.343	3.6	77.9	18.7	0.6	100.6	26.0
	C	42–60	46.96	42.92	10.12	1.61	1.85	12.25	.151	8.6	31.3	8.1	2.3	50.3	18.7
	A	0–9	46.67	40.52	12.81	1.65	1.95	9.63	.203	25.3	82.3	28.7	1.9	138.2	27.9
	B	9–28	46.27	38.53	15.20	1.62	2.03	8.06	.252	13.9	66.0	24.6	4.8	109.3	18.2
	C	28–50	47.35	41.64	11.01	1.64	1.93	11.38	.169	7.5	42.7	21.0	0.6	71.8	14.1
	A	0–7	48.30	37.39	14.31	1.76	2.19	8.92	.246	20.0	74.9	22.9	4.5	122.3	25.2
	B	7–32	50.36	33.25	16.39	1.98	2.57	8.13	.316	15.7	76.9	27.4	3.9	123.9	25.7
	C	44–60	50.36	40.68	8.96	1.84	2.10	14.86	.141	12.8	31.7	13.0	2.6	59.9	15.0
	A	0–10	41.22	43.57	15.21	1.31	1.60	7.16	.224	18.9	68.5	20.0	0.6	108.0	22.5
	B	10–30	45.27	39.58	15.15	1.55	1.94	7.90	.245	12.5	60.0	20.2	0.6	93.3	19.9
Harford Co., Md.	A	1–9	45.60	37.57	16.83	1.60	2.06	7.18	.287	18.6	63.5	22.5	2.9	107.5	19.9
	B	9–28	46.33	35.83	17.84	1.66	2.19	6.87	.319	11.4	34.7	21.7	1.9	69.7	18.1
	C	40–60	41.22	37.26	21.52	1.37	1.87	5.07	.370	11.1	42.2	20.6	5.8	79.7	12.0
Montgomery Co., Md.	A	0–8	41.81	37.32	20.87	1.49	1.90	5.30	.359	12.8	58.0	17.2	1.6	89.6	22.7
	B	8–34	46.60	33.53	19.87	1.77	2.35	6.22	.379	16.1	68.5	21.2	1.6	107.4	26.9
	C	54+	44.18	36.20	19.62	1.55	2.07	5.96	.347	16.8	48.6	27.2	4.2	96.8	13.5
Montgomery Co., Md.	A	0–8	48.59	37.36	14.05	1.77	2.20	10.01	.222	34.6	11.4	27.4	10.6	84.0	29.0
	B	8–32	52.27	34.61	13.12	1.79	2.56	10.54	.243	23.2	63.5	39.3	8.4	134.4	22.7
Mean Values	A		44.65	38.82	16.53	1.54	1.96	7.51	.273	20.5	77.5	20.9	3.5	122.4	25.6
	B		46.94	35.39	17.42	1.69	2.26	7.36	.323	13.6	69.9	24.2	3.0	110.6	21.9
	C		45.53	38.69	15.77	1.59	2.00	9.06	.271	11.8	46.8	19.0	3.0	80.6	15.3

TABLE III (Continued)
Chemical Constituents of Colloids characteristic of Various Soil Series

Location of Profile	Horizon	Depth	Chemical composition calculated on the basis $SiO_2+Al_2O_3+Fe_2O_3=100$			Molecular ratios				Monovalent and divalent basis calculated as milliequivalents per 100 grams					Total base exchange capacity by $BaCl_2$
		inches	SiO_2 per cent	Al_2O_3 per cent	Fe_2O_3 per cent	$\frac{SiO_2}{Al_2O_3+Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	Ca milli-equiv-alents	Mg milli-equiv-alents	K milli-equiv-alents	Na milli-equiv-alents	Total milli-equiv-alents	milli-equiv-alents
Colloids of the Cecil Series															
Goochland Co., Va.	A	0–8	49.07	40.53	10.39	1.77	2.05	12.50	.164	4.3	38.7	17.0	3.6	63.6	9.0
	B	12–30	44.67	41.89	13.44	1.50	1.81	8.80	.205	1.8	25.8	9.8	1.9	59.3	8.3
	C	60+	44.53	39.66	15.81	1.51	1.90	7.45	.255	2.9	27.8	8.9	1.6	41.2	7.6
Rockingham Co., N.C.	A	4–10	44.71	41.34	13.94	1.51	1.83	8.48	.216	7.1		21.9	0.6	—	8.0
	B	16–38	44.66	41.49	13.85	1.50	1.82	8.54	.213	5.4	11.9	13.6	0.6	31.5	6.9
	C	70+	43.74	40.73	15.53	1.46	1.82	7.47	.243	1.4	10.4	8.9	1.6	22.3	5.8
Davie Co., N. C.	A	1–8	49.44	40.33	10.23	1.78	2.08	12.81	.162	2.5	20.8	15.5	0.6	39.4	13.7
	B	20–50	45.99	39.69	14.32	1.59	1.96	8.51	.231	11.1	24.8	7.6	0.8	43.8	9.6
	C	50+	45.39	39.38	15.23	1.55	1.95	7.89	.247	11.1	25.3	21.3	0.6	58.3	10.5
Rutherford Co., N. C.	A	0–5	41.78	44.59	13.63	1.33	1.59	8.12	.196	7.9	27.8	7.4	1.9	45.0	9.4
	B	5–36	38.26	44.18	17.56	1.18	1.47	5.77	.254	8.9	6.5	3.8	4.2	23.4	5.6
	C	72–96	36.10	50.13	13.77	1.03	1.21	6.94	.174	8.2	6.9	3.8	2.9	21.8	7.0
Clarke Co., Ga.	A	1–5	42.12	46.21	11.67	1.33	1.54	9.56	.161	7.5	6.5	22.1	0.6	36.7	10.7
	B	5–60	39.92	45.90	14.18	1.35	1.48	7.46	.198	5.0	26.8	10.8	1.0	43.6	7.3
	C	110–130	40.47	41.30	18.23	1.29	1.66	5.87	.282	7.1	25.3	7.9	1.6	41.9	7.2
Wilkes Co., Ga.	A	0–9	41.90	44.50	13.60	1.34	1.34	8.16	.195	11.1	20.3	8.7	3.2	43.3	18.0
	B	9–36	39.72	47.77	12.51	1.20	1.20	8.41	.167	12.5	11.4	7.4	0.3	31.6	12.5
Troup Co.,Ga.	A	2–6	44.26	45.19	10.54	1.42	1.55	11.11	.150	8.9	17.9	21.3	0.6	48.7	10.0
	B	20–35	42.14	40.51	17.35	1.39	1.51	6.33	.275	0.7	5.0	9.6	4.8	18.7	6.6
	C	75–90	45.65	42.03	12.32	1.55	1.49	9.79	.188	2.5	2.0	13.6	0.6	18.7	5.7
Chambers Co., Ala.	A	0–7	41.97	42.71	15.32	1.12	1.12	7.24	.230	10.4	22.3	6.4	1.6	40.7	14.0
	B	8–24	40.81	41.08	18.11	1.31	1.31	5.96	.283	2.9	8.9	6.4	2.3	20.5	8.1
	C	25–59	42.43	40.11	17.46	1.40	1.40	6.43	.279	0.7	3.5	7.9	5.5	17.6	10.3
Mean Values	A		44.41	43.18	12.42	1.45	1.64	9.75	.184	7.5	22.0	15.0	1.6	45.3	11.6
	B		42.02	42.81	15.17	1.38	1.57	7.47	.228	6.0	15.1	8.6	1.9	34.1	8.1
	C		42.62	41.91	15.48	1.40	1.63	7.41	.238	4.8	14.5	10.3	2.1	31.7	7.7

also to be kept in mind that the consequences, as well as the degree of dispersion, are modified by the quantity of water entering into the operations, and by the character and quantity of the materials through which percolating waters must pass, as well as by erosional effects both at the surface and within the body of soil and soil material.

From Table II it will be noted that when the analytical data are recalculated so that the sum of the three chief constituents equals 100%, certain marked differences are evident in the different groups. In the pedocals the silica, alumina and iron oxide content is nearly constant. In the case of the Amarillo there are two distinct series of layers, 1 to 3 and 3 to 6. In each a layer is marked by the fundamentally characteristic accumulation of calcium carbonate. In the third stratum the quantity of CO_2 is 0.35%; in the fifth 11.82%.[1] In the soil itself the percentages were not determined. The field data, as collected by the Soil Survey indicate clearly that the lower set of strata represents an old and buried soil and, indeed, this fossil soil had reached a much higher degree of maturity than the present soil. The material from which both were developed is of the same character. These facts make the essential constancy of the colloid composition the more striking and illuminating. The maximum range of silica throughout the profile is 1.62%; of alumina, 1.75%; of iron-oxide, 1.58%. This constancy is also revealed by the molecular ratios of silica to alumina, a range between 3.60 and 3.88; of silica to iron oxide, between 15.19 and 16.57 for the solum, and in the whole profile between 15.19 and 17.99, and of silica sesquioxide between 2.97 and 3.18. This latter value is about fifty per cent greater than is required for the composition of kaolin.

The combined water also is strikingly constant. If we eliminate carbon dioxide loss and the loss due to organic matter and recalculate the data for the Amarillo profile, the range for the first four layers is 8.06, 7.36, 7.90 and 7.76. This constancy of the composition of the colloid of the various horizons is the more remarkable in view of the range of the mechanical composition of the soil.[2] The inorganic colloid content is 23.9% for the first horizon and 42.8% for the second. When we turn to the content of bases in the soil colloid the following relations appear. The magnesium content is high as compared with the other bases, and its constancy in the profile, except in the first horizon, leads to the suspicion of the presence of undecomposed minerals in the colloid, or of the existence of the same definite complex in all horizons, especially when considered along with the like constancy and high content of potassium. The high total base content in comparison with the total base exchange capacity and the total exchangeable base are in accord. The fact that in each horizon the excess of exchangeable base over the total base exchange capacity, as determined by the use of normal barium chloride, accords with the pH values of the whole soil. These values are, for the respective horizons, 6.5, 7.8, 7.8, 7.9 and 8.3.

[1] Anderson and Byers: U.S.D.A. Tech. Bull., **229** (1931).
[2] Anderson and Byers: Loc. cit.

The same relations shown by the Amarillo profile are also shown by the Barnes profile with such exceptions as are to be expected from the facts that the Barnes soil is developed near the east side of the Chernozem area and therefore under higher rainfall and from calcareous glacial drift instead of calcareous sand and clay. There is a somewhat greater contrast between the C horizon and the A and B in respect to silica-alumina ratio and the silica-sesquioxide ratio. There is also shown by the distinct though slight change of silica alumina ratio, and the very marked alteration of the silica-iron ratio between the A and B horizon, definite indication of a concentration of alumina and of iron-oxide in the B horizon at the expense of the A, a process most marked in the podsol and podsolic soils of the humid regions.

The most interesting difference between these profiles is the difference between the calcium and magnesium content of the A horizon as compared with the B. In general, it may be said that the A horizon is enriched by the ash content of the plants, a part of which is derived from the B horizon. The Barnes profile, with its abundant organic matter, shows this relation for calcium and potassium and a marked decrease in magnesium content, while the Amarillo shows a slight decrease in calcium, and the expected decrease in magnesium and a very slight excess of potassium in the A horizon of the colloid as compared with the B horizon. This analytical difference in the potassium is very slight and probably not real, since the reverse relation is shown by the soil itself. The explanation of these differences is found in the greater rainfall and more luxuriant vegetation of the Barnes compared with the scanty rainfall and light vegetative cover of the Amarillo.

There is revealed in the data so far assembled no evidence of any free sesquioxide in the Amarillo colloid and of but small quantities of free oxide of iron in the Barnes.

The greater concentration of colloid in the B horizon of the Amarillo and the Barnes, as revealed by mechanical analysis, may either be due to colloidal-freshet-erosion from the A horizon into streams, or to eluviation from the A and concentration in the B horizon. If the latter, then the evidence points toward the transfer of the constituents as a whole, and to the existence of definite complexes, acidoids, of the silica with alumina and iron oxide.

The data given in Table II for the podsols offer some interesting contrasts. The podsols have two distinct portions of the A horizon, the surface layer high in organic matter and the highly leached "bleicherde." The A horizons are invariably high in silica and low in alumina and iron oxide, when the major inorganic constituents are alone considered, as compared with the B horizon. The silica-alumina ratio for the colloid of the Superior fine sandy loam is the highest yet noted in our analyses, and in the two other podsols is of the same order of magnitude as in chernozem colloids. The silica-iron ratio is exceedingly high, although quite appreciable quantities of iron compounds are present, both in the soil and colloid. That free hydrated iron oxide is not present in the A horizon is indicated not alone by this ratio but also by the color of the colloid and of the soil. By contrast in the B horizon, the silica sesquioxide ratio is low and in the Beckett profile reaches o.86 in the B stratum, a value

approaching that of laterites.   The silica-alumina ratio is, however, relatively much higher, the minimum being 1.83, which is close to that of true clay.

The silica-iron oxide relations are very illuminating.   In every case this ratio is markedly different from that in the A horizon, the maximum variation being 18.30 in the A to 1.58 in the B.   It is to be noted that in this comparison the total silica is considered.   These facts and the color of the B horizon and its colloids leaves no element of doubt that in the podsols the B horizon represents a zone of enrichment at the expense of transportation of material from the A horizon and that the transportation, so far as *segregation of materials is concerned*, is almost, if not quite, wholly of hydrated oxide of iron.   That this is true is also indicated by the relatively small increase in the percentages of colloid material in the A_1 and B_1 horizons.   These are for the Becket from 3.9% to 5.8% and from the Superior 1.6 to 4.9.   In this connection it may also be mentioned that the B_1 horizon is a zone of greater enrichment than is B_2, a fact which would seem to indicate that the concentration of the colloid is the result of a species of filtration in which suspended colloid, the dispersion or solution of which is favored by the organic matter in the surface, is flocculated, or precipitated, by the higher alkalinity of the subsoil, especially when it is young.   (These relationships are not new but have been frequently referred to in studies of the whole soil).   When the B horizon is once established as a zone of accumulation it becomes a more effective filter, or may even become impervious.

The quantity of bases present in the colloid of the podsol is notably less than in the chernozem soils and, except in the A_o horizon, the base holding capacity is also somewhat smaller.   In the A_o horizon the high base holding capacity is increased by the presence of organic matter, this relation being characteristic of organic matter.   The base exchange content of the podsols is notably less than in the chernozem and by consequence the degree of saturation.   The greater quantity of calcium in the organic layer and the smaller quantity of magnesium occurs in all three soils.   The increasing quantities of magnesium in the C horizon point to the presence of unhydrolyzed, or at least, less hydrolyzed minerals in the colloid of this horizon.

We may now turn to a consideration of the gray-brown podsolic soils.   We find in Table II the mean of eight profiles of Miami, six A and B horizons of the Leonardtown, and six profiles and two additional A and B horizons of the Chester soils.   The details for each soil are given in Table III.

The Miami soils are developed from calcareous glacial drift under deciduous forest cover and under higher temperature and somewhat smaller rainfall than the podsols.

The Leonardtown is developed from the sandy material of the coastal plain and the Chester from gneisses and shale.   The Leonardtown and Chester are developed at a much higher mean annual temperature than is the Miami, though also under forest cover, mainly deciduous.

In the Miami series the silica-sesquioxide ratio is much lower than in the pedocal soils and also very much lower than in the A horizons of the podsols, while it is much higher than in the podsol B_1 and B_2.   On the other hand, the

silica-alumina ratio is of the same order of magnitude as that of the chernozems. The cause is evident from the silica-iron oxide ratio which is materially and invariably less in the B than in the A. (It is to be noted from the depth measurements that none of the A_0 horizons of the Miami samples were analyzed. These examinations were for a purpose other than that of the present considerations.)

Insofar as podsolization is regarded as a segregation or fractionation of colloidal material, it is evident that the effect is chiefly upon the iron oxide content of the colloids. That eluviation has occurred to a large extent is evident from the fact that in the Miami soils the colloid content of the B horizon[1] is invariably very much greater, from 50% to 400%, than in the A. It is recognized, of course, that this colloid deficiency in the A horizon is due in part to erosion (horizontal elutriation) but it must also be due to eluviation (percolation or perpendicular elutriation).

In the Miami soils the total bases in the B horizon are of the order of magnitude of the pedocals and are somewhat less in the A horizon. The calcium content is undoubtedly greater in the A_0 horizon (not shown in the tables) but the fact is indicated clearly by the complete analyses of Miami soils on file in the Bureau. The total base content of the Miami soils is greater than that of the podsols and less than that of the chernozem, while the total base exchange capacity is less than either. These facts are indicative on the one hand of somewhat greater hydrolysis in the Miami and a considerably more effective leaching. Unfortunately, the base exchange content of these samples was not determined so that the degree of saturation is not available.

When we turn to the Leonardtown series we find a marked decrease in the silica sesquioxide ratio as compared with the series previously discussed, but the silica-alumina ratio is still well above 2 and is less in A horizon than in the B. The podsolic effect is most largely shown by the shifting of the iron oxide. The total base exchange content and the total base exchange capacity are both much less than in the Miami series. These facts are in accord with the general effect to be expected from the greater hydrolysis at higher temperature, and indicate extensive hydrolysis and the elimination of the freed bases and of silica. The strikingly small base exchange capacity in spite of the high silica alumina ratio also points to quartz particles in the colloid, a supposition in harmony with the very large content of silt in the soil which is upwards of 50%.[2] The most striking characteristic of this series is the uniformity of the colloid composition.

The mean values of the colloid from the Chester series are given in Table II. These include six complete profiles and two additional profiles of two horizons given in detail in Table III. In this soil the silica-sesquioxide ratio is well below 2, while the silica-alumina ratio is 1.96 in the A horizon and 2.26 in the B. This is in strong contrast with the reverse relations in the podsols and Miami and the practical absence of such relation in the pedocals. The same difference is shown to a less degree in the Leonardtown series. There is

[1] Holmes and Edington: U.S.D.A. Tech. Bull., **229**, 7 (1930).

[2] Slater and Byers: U.S.D.A. Tech. Bull., **232**, 18 (1931).

not in the Chester series so marked evidence of segregation of iron-oxide, though the increase of the silica-alumina ratio in the B horizon and the decrease of the silica-iron ratio being opposed indicate considerable differentiation. This differentiation is shown by the iron-oxide-alumina ratio which is considerably greater in the B than in the A, as is the case in all the podsols and podsolized profiles. This differentiation in the B horizon is further emphasized by consideration of the mean value of the colloid content, which is 17.6% in the A horizon and 27.6% in the B.[1]

The total bases of the Chester are of the same order of magnitude as those of the Leonardtown series. The mean values are slightly higher but this is due chiefly to one sample from Chester Co., Pennsylvania, in which the magnesium content in the A and B horizon is abnormally great. Mean values of the magnesium content and the greater content in the A horizon as compared with the B would seem to indicate the presence of some partially hydrolyzed magnesium silicate in the colloid. The low base exchange capacity of the colloid indicates a degree of leaching approaching that of the red soils given in the next group. It will be noted that the base exchange capacity of the A horizon is greater than that of the B, owing to the higher base exchange capacity of the organic matter.

Why a similar relation does not appear in the Leonardtown series is not clear since the mean percentages of the organic matter are 7.11% for the Chester (Holmes and Edgington: Tech. Bull., 229, 12) and 7.66% for the Leonardtown (Holmes: J. Agr. Res., 36, 464, (1928)). The explanation in the case of the Miami may be in the fact that the A_0 portion of those profiles, high in organic matter, was not analyzed. Nevertheless, in the A_1 and B in the Miami the organic matter mean values are 5.95% and 1.98% respectively. In these profiles the usual relation of higher base content in the A horizon obtains.

The red soils given in the next section of Table II are the Davidson and the Cecil. The data for the Cecil are the mean values for a series consisting of seven profiles of three horizons and one of only the A and B. The detailed data for these profiles are given in Table III.

The Cecil soils are derived from highly weathered gneiss or schists and the Davidson from diabase, basalt or other quartz free igneous material (Marbut). These two soil series may be described as lateritic, though not yet laterites. The colloid content of the Davidson soil is very high. As determined by the water vapor absorption method it is 27.3, 64.8, 66.5 and 29.6 for the respective horizons given in the table (Anderson and Byers: Bull., 228, 17). The mean values for the Cecils are 11.4 and 42.2% for the A and B horizons. In these soils the silica sesquioxide ratio lies well below the value of two in both soil series, and that of the silica-alumina in the Cecil is also much below two. In the Davidson soil the silica-alumina ratio is well below two in the A horizon and almost exactly two in the B_1, B_2 and C horizons.

Even if we assume that all the iron-oxide exists as free hydrate and that in these colloids there are no free quartz particles or free hydrated silica, it is

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[1] Holmes and Edgington: Bull., 229, 8 (1930).

difficult to avoid the conclusion that free alumina, more or less hydrated, exists in these lateritic soils. In the B horizons the silica-iron ratio in both series is well below that of the A and indicates a distinct segregation by transfer of iron oxide to the B horizon to a greater extent than the corresponding transfer of alumina (podsolization). The same result is indicated by the iron oxide-alumina ratio. This podsolization process is more distinctly marked in the Davidson than in the Cecil profiles. It may be remarked parenthetically that podsolization is a species of natural fractionation of colloid material and that in the near future I. C. Brown of the Bureau will publish the results of his efforts to accomplish the same result by laboratory methods.

In these colloids great extent of leaching is indicated by the very low values of the base content and in particular that of calcium. The extreme degree of hydrolysis is indicated by the low base exchange capacity of the colloids. In both of these respects the weathering has proceeded much farther in the Cecil than in the Davidson soils. In view of the fact that we are dealing here with only one profile of the Davidson and with a very diverse set of Cecil profiles, the above general statement may seem over-bold, but it should be remembered that the work on the Miami, Chester, Leonardtown and Cecil soils indicates a very great degree of constancy in the colloid of a given soil series whatever may be the location of the individual sample provided only that the sample be a fair representative of the series.

When we come to a consideration of the only true laterite we have studied we find the process of hydrolysis and of leaching carried almost to the practical limit. This means the complete conversion of the silicates to alumina and iron oxide and the removal of the bases and also of silica by leaching. In the Nipe soil this is carried to practical completion, the silica-sesquioxide, silica-alumina and the silica-iron oxide ratios all falling to fractional values. Even in this soil the process of podsolization is still detectable in the relation between the silica and iron oxide and between the iron oxide and alumina. Also in this soil the higher value of the silica-alumina ratio, distorted as it is by the material being essentially an iron ore, indicates the reluctant yielding of the alumino-silicates to weathering, a fact also attested by the abundance of clay in the surface of the lithosphere. In this ferruginous laterite the total bases become extremely small and calcium is absent except in the surface layer. The total base holding capacity also becomes an almost vanishingly small quantity.

The Nipe represents, therefore, a soil that has completed its course and is essentially dead, a condition recognized by plants which, on this soil, are scanty and ill nourished. We have no corresponding soils in the United States, so far as the writers are aware. In the Bureau we have analyses of the colloid from a fossil aluminous laterite (Anderson and Byers: Bull., 229, 17) and of a deep layer from a similar material from Costa Rica (Anderson and Mattson: U.S.D.A. Bull., 1452, 2) in which the relations are of the same type. In the former the silica sesquioxide ratio is 0.84 and in the latter 0.55. They are not true soils, and are not included in Table II.

We may now, having traced the chemical relationships from West to East and from North to South, return to a consideration of the data contained in the last section of Table II. This section gives the composition of the colloid of the Marshall silt loam from Case County, Nebraska, recalculated from data found in U.S.D.A. Bulletin 1311 (Robinson and Holmes: "The Chemical Composition of Soil Colloids") and of the Shelby silt loam from Bethany, Missouri, recalculated from data soon to be published by C. S. Slater of the Bureau of Chemistry and Soils. These are prairie soils (see Marbut's classification, Table I) and are derived, according to Dr. Marbut, from loessial material in the case of the Marshall and from somewhat calcareous glacial drift in the case of the Shelby. In both soils the dominant vegetation is grass and the temperature and mean rainfall moderate.

The silica-sesquioxide, silica-alumina and silica-iron oxide ratios all show them to be closely related to the chernozem soils. The silica-alumina ratio indicates that hydrolysis has not reached the point where appreciable fractionation of the aluminous silicate has occurred by eluviation. The silica-iron oxide and iron oxide-alumina ratios indicate a certain but limited podsolization. That leaching has proceeded to a very limited degree is clearly indicated by the large values of the basic components and by the very slight concentration of calcium and total bases in the A horizon. The base exchange capacity and the degree of saturation of these colloids have not been accurately determined for the Marshall by methods comparable with those used for the other colloids. The values for the Shelby, however, show that both are essentially saturated soils. The lower horizons of the Shelby profile represent the composition of the glacial drift from which the solum is derived.

The mechanical analysis of the Shelby profile shows about 100% increase in the quantity of colloid in the lower horizons. As determined by the pipette method the percentages are 25.1, 49.6, 46.0, 37.9, 29.8, 31.0, 18.5 and 36.1%, and by the vapor absorption method 23.1, 49.6, 37.2, 27.0, 26.8, 16.5 and 30.6. In this case, then, as in the chernozem soils, the removal of the colloid from the A horizon may be ascribed to horizonal elutriation, erosion, or to eluviation. That the former is effective is evidenced by the character of the streams, especially in freshets, which traverse the prairie soils. That perpendicular erosion, eluviation, also occurs is evident from the data given. If so, it is clear that the transfer is of the colloid as a whole. The conclusion is clear that the colloidal complex in these soils is an essential unit, as contrasted with the colloid of the podsols and of the podsolic soils.

The essential characteristics of the prairie soils as represented by the Marshall and the Shelby series are those of the chernozem, modified by the absence of the zone of carbonate accumulation, due to adequate rainfall for percolation throughout the profile and by incipient podsolization. In these series there is but faint indication of laterization, but in the prairie region the soil surveys show the existence of soil series in which there is no doubt that examination will reveal the evidence of the active operation of this process. The chemical characteristics of the colloids of the prairie soils are in harmony with the high degree of fertility of these soils.

Summary and Conclusions

The striking differences shown by the colloids of the great soil groups given in Category 4 of Table I clearly reflect the field differences upon which the classification is based. The analyses show that the process of podsolization, fractionation of colloids, occurs wherever humid conditions are adequate to permit extensive leaching of the products of soil hydrolysis. They also show that the hydrolytic effects of water are greater, the higher the temperature. It is also clear that not only is the soil making process affected by moisture and temperature, but by the character and quantity of the vegetation upon the soil and that in turn the soil condition is reflected by the character and quantity of the vegetation it will support.

Two rather important inferences from differences between the colloids discussed may be drawn. When soils have but little colloid content it is well known that all attempts to build up a permanent store of available plant food are useless, since percolation rapidly removes the material not used practically at once. Yet such soils are not valueless, as many of the soils of Florida witness. It would appear from the data of Tables II and III that similar attempts with laterites and highly ferruginous soils are almost equally futile. Such soils must be "spoon fed." On the other hand, chernozem, prairie, podsol and podsolitic soils may, if exhausted of their exchangeable base content by over-cropping, be restored to their pristine productivity, provided they be not ruined by erosion, by the proper use of adequate fertilization, or perhaps even by the lapse of adequate time for non-exchangeable bases to become available, and that this renewal is, in a manner of speaking, a permanent restoration.

The other inference requires for its full substantiation a more elaborate discussion and fuller evidence than can be presented in this paper. It is, briefly, as follows: The progressive hydrolysis of the soil forming minerals results *primarily* in the production of an acid complex, probably polybasic, consisting of an alumino-silicic acid radical, in which silica-alumina ratio is greater than two, and in which, as a soil colloid, the acid hydrogen is partially replaced by bases. The salts of this acid, as well as the acid itself, are extremely slightly soluble in water. The details of the structural relations of this acid complex will vary with the structure of its parent material, and with the degree to which iron replaces aluminum in the mineral silicate. The existence of this complex in the colloids of the prairie and podsol soils is rendered extremely probable by the X-ray examinations carried out by Hendricks and Fry[1] and by subsequently obtained, unpublished data, on the Amarillo colloid. In these colloids the X-ray diffraction patterns are those of montmorillonite or ordovician bentonite, the latter term being taken to indicate the presence in the material of quartz. The presence of quartz thus indicated may be considered as due to primary quartz or to silicic acid freed as a result of hydrolysis. As hydrolysis proceeds the alumino-silicate is converted next to a complex having a silica-alumina ratio of two, and, since the iron compounds apparently are more easily hydrolyzable than are the corresponding alumino-

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[1] Soil Science, **28**, 457-479 (1930).

silicates, the colloid complex contains iron chiefly as the hydrated oxide. The hydrolytic influence being favored by time, high temperature and much moisture, eventually produces a complex consisting essentially of hydrated oxides and, with extensive percolation, eventually of those of iron and aluminum alone. At any stage of hydrolysis all of these various compounds may be present and the character of the colloids be dependent upon which stage of hydrolysis is dominant, and to what degree removal of products by water has proceeded.

This conception of the soil colloid necessarily envisages the possible presence, or, better perhaps, probable presence, of colloidal sized particles of quartz and of unhydrolyzed minerals in most colloids.

A soil colloid is, therefore, not to be regarded as a single complex, even if the inorganic portion be considered alone, but as a system not in equilibrium, but proceeding, at a rate determined by environmental conditions, from its birth in the rocks to its ultimate end, a dead soil—the laterite.

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