CLAY FORMATION AND ACCUMULATION IN SELECTED OKLAHOMA SOILS*

by

FENTON GRAY, L. W. REED, and H. D. MOLTHAN
Oklahoma State University, Stillwater, Okla.

ABSTRACT

The clay minerals were studied from eleven soil profiles representing three Great Groups of eastern and central Oklahoma. Montmorillonite and illite type clay minerals were found to be the dominant minerals; montmorillonite dominates the fine clays; illite is the chief constituent of the coarse clays. The fine clays dominated the clay fraction of most horizons, including the parent material. The results of the investigation indicate that the present régime of soil formation has had little effect in altering the clay minerals of the soil from those present in the original sediments.

INTRODUCTION

Studies have been made on eleven soil profiles representative of the Prairie, Planosol, and Reddish Prairie Great Soil Groups.† All of these soils were developed under tall grass vegetation, and occur in central or east-central Oklahoma, and are agriculturally important.

Chemical, physical, and mineralogical analyses along with descriptions were made in order to characterize the soils and provide a better basis for their classification. The purpose of this paper is to summarize the results obtained from the studies that have been completed in regards to the amounts and kinds of clays present in Oklahoma soils. A knowledge of the clay mineralogy would not only aid characterization and classification of Oklahoma soils but would aid in relating plant growth to physical conditions and fertility problems of the soils studied.

MATERIALS AND METHODS

The soil profiles that were sampled by horizons for study (Table 1) are: two of Dennis, a Prairie Soil, one of Parsons, a Planosol, and two each of Kingfisher and Kirkland, Reddish Prairie Soils, and four of Zaneis, a Reddish Prairie Soil.

---

* Research reported in this publication was done under Oklahoma Agricultural Experiment Station Project Number 868, and was presented at the Eighth Conference, in Norman, Okla.

† Yearbook, Soil of the United States, U.S.D.A. Soils and Men (1938). The Dennis would have been classified as Bates and the Kingfisher as Zaneis.

TABLE 1.—SOIL SERIES, GREAT SOIL GROUP, PARENT ROCKS AND NATIVE VEGETATION FOR SOIL PROFILES STUDIED

Soil Series	County Location	Parent Rock	Native Vegetation
Dennis #1 Prairie	Wagoner	Pennsylvanian Sandy Shales	Tall Grass Prairie
Dennis #2 Prairie	Pawnee	Pennsylvanian Sandy Shales	Tall Grass Prairie
Kirkland #1 Reddish Prairie	Oklahoma	Permian Clayey Shales	Tall Grass Prairie
Kirkland #2 Reddish Prairie	McClain	Permian Clayey Shales	Tall Grass Prairie
Parsons Planosol	Mayes	Pennsylvanian Shales	Tall Grass Prairie
Zaneis #1 Reddish Prairie	Payne	Permian, Wellington, Formation, Shale and Sandstone	Tall Grass Prairie
Zaneis #2 Reddish Prairie	Payne	Permian, Wellington Formation, Shale and Sandstone	Tall Grass Prairie
Zaneis #3 Reddish Prairie	Oklahoma	Permian,Garber Formation, Shale and Sandstone	Tall Grass Prairie
Zaneis #4 Reddish Prairie	Oklahoma	Permian,Garber Formation, Shale and Sandstone	Tall Grass Prairie
Kingfisher #1 Reddish Prairie	Kingfisher	Permian, Hennessey Formation, Cedarhill Sandstone	Tall Grass Prairie
Kingfisher #2 Reddish Prairie	Kingfisher	Permian, Hennessey Formation, Flowerpot Shale	Tall Grass Prairie

SAMPLE PREPARATION AND FRACTIONATION

A 150 to 400 g sieved sample of soil from each horizon was treated with H_2O_2 to remove organic matter. The clays were separated and fractionated according to a method outlined by Jackson *et al.* (1949). The clay fraction of less than 2 microns was divided into two clay fractions by using a Sharples supercentrifuge, 2 to 0.1 or 0.2 microns as coarse clay and less than 0.2 or 0.1 micron as fine clay. The percentage of fine clay was determined by the centrifuge method of Steel and Bradfield (1934). For more details refer to published works, Wilkinson and Gray (1954), Fanning and Gray (1959) and Molthan (1960).

ANALYSIS OF CLAY FRACTIONS

For determining the cation exchange capacities of the two clay fractions, the Ba-replacement method of Whitt and Baver (1937) was employed with the exception of Molthan (1960), who used a special adaptation of the Gedroiz method by Kelley (1948). In this method, Mg saturated clay samples were placed in fritted glass leaching tubes and the Mg extracted by 1 N NH_4Cl and read directly on the Beckman DU flame spectrophotometer with photomultiplier attachment.

Non-exchangeable K was determined by a modification of the carbonate fusion method of Hall (1937). Molthan used the hydrofluoric acid dissolution method of Jackson (1958).

Ethylene glycol retention values were determined by the method of Dyal and Hendricks (1950) except for Molthan, who used the method reported by Martin (1955). All surface area data presented in this report were compared to pure reference minerals. The two slightly different methods gave comparable results.

The clay fractions were prepared for X-ray and DTA analyses according to the methods outlined by the S-14 committee.*

Data other than the clay mineral distribution were, organic matter, pH, cation exchange capacity, and base saturation; however, only data from samples of four of the soil profiles are included in this paper. The pH was determined with a Beckman glass electrode pH meter on a 1:1 soil–water mixture. The percent organic matter was determined by the potassium dichromate wet oxidation method of Scholenberger (1931). Cation exchange capacity and exchangeable cations of the whole soil were determined by the method of Peech *et al.* (1947).

CHARACTERISTICS OF PRAIRIE, PLANOSOL, AND REDDISH PRAIRIE SOILS

The Prairie Soils are represented by Dennis which is described as follows:

Location: Wagoner County, Oklahoma; 3½ miles north-west of Wagoner (SW¼SW½ sec. 29, T. 18 N., R. 18 E.). The sampling site is a native bluestem meadow of good vigor and density on gently sloping, erosional upland with a convex surface and gradient of 1½ per cent.

---

* The methods are outlined in Southern Cooperative Series Bulletin 61 which consists of a report of cooperative research under Southern Regional Project S-14. Under provisions of the S-14 committee, X-ray diffractograms and DTA were made by S. B. McCaleb at North Carolina State University and G. W. Kunze of Texas A and M College.

Horizon	Depth Inches	Description
A_1	0–12	Very dark grayish brown (10YR 3/2; 2/2m) silt loam; moderate fine and medium granular; pH 5.4; grades to horizon below.
A_3	12–16	Very dark grayish brown (10YR 3/2; 2/2m) silt loam; moderate fine and medium granular; pH 5.4; grades to horizon below.
B_1	16–26	Grayish brown (10YR 5/2; 4/2m) silty clay loam; moderate medium subangular blocky to coarse granular; fine black concretions and a few rounded siltstone fragments; pH 5.6; grades to horizon below.

Horizon	Depth Inches	Description
B_2	26–31	Grayish brown (10YR 5/2; 4/2m) silty clay; moderate medium subangular blocky; fine black concretions and a few rounded siltstone fragments; pH 5.8; grades to horizon below.
B_3	31–40	Grayish brown (10YR 5/2; 4/2m) silty clay; compound weak coarse blocky and moderate medium subangular blocky; firm; slowly permeable; a few fine rounded siltstone fragments; pH 5.9; grades to horizon below.
C_1	40–54	Grayish brown (10YR 5/2; 4/2m) clay; weak blocky; a few fine rounded siltstone fragments; fine concretions and medium to coarse accretions numerous; pH 6.3; grades to horizon below.
C_2	54–72	Light brownish gray (10YR 6/2; 5/2m) light clay; weak blocky; pH 6.6; This is only partially altered shale.
C_3	72–90	Mottled brownish yellow (10YR 6/7; 5/8m) and gray (10YR 6/1; 5/1m) light clay; a few medium concretions and soft, black accretions; pH 6.6; this is weakly blocky, partially altered shale of neutral reaction.

The Planosol Soils are represented by Parsons which is described as follows: Location: Mayes County, Oklahoma; 1½ miles west of Adair (NW¼NW¼ sec. 32, T. 23 N., R. 19 E.). The sampling site is a native bluestem meadow of good vigor and density on nearly level upland with plane to weak convex surfaces and a gradient of about ½ per cent.

Horizon	Depth Inches	Description
A_{11}	0–6	Dark grayish brown (10YR 5/2; 3/2m) silt loam; weak to moderate medium granular; pH 5.7; grades to horizon below.
A_{12}	6–10	Dark grayish brown (10YR 4/2; 3/2m) silt loam; weak to moderate medium granular; pH 5.2; clear boundary to horizon below.
A_{21}	10–14	Light brownish gray (10YR 6/2; 5/2m) silt loam; weak medium granular; pH 5.5; clear boundary to horizon below.
A_{22}	14–16	Light brownish gray (10YR 6/2; 5/2m) silt loam; porous, massive; pH 5.6; abrupt boundary to horizon below.
B_{21}	16–22	Very dark grayish (10YR 3.5/2; 3/2m) brown; weak coarse blocky; very slowly permeable; side of peds strongly coated with light gray films; pH 5.4; grades to horizon below.
B_{22}	22–28	Much like the layer above, but dark brown (10YR 3.5/3; 3/3m) clay; pH 5.3; grades to horizon below.
B_{31}	28–37	Light yellowish brown (10YR 6/4; 5/4m) clay; weak coarse blocky; very slowly permeable; a few fine rounded siltstone fragments and small black concretions; pH 5.3; grades to horizon below.
B_{32}	37–43	Grayish brown (10YR 5/2; 4/2m) weak coarse blocky; very slowly permeable; a few fine round black concretions; slightly less compact than layer above; pH 5.4; grades to horizon below.
C_1	43–66	Coarsely mottled light (10YR 7/1; 6/1m) gray, strong brown (7.5YR 5/6; 4/6m) and yellowish-brown 10YR 5/4; 4/4m clay; massive; firm; slowly permeable; cluster of white gypsum crystals common; pH 5.4; grades to horizon below.

Horizon	Depth Inches	Description
C_2	66–84	Coarsely mottled yellowish brown (10YR 5/6; 4/6m) and gray (10YR 6/1; 5/1m) clay; massive; compact; slowly permeable; a few rounded chips of siltstone and small pockets of white gypsum crystals, pH 5.6. This is only partially altered clay shale but is slightly more compact than the material in the C_1 layer above.

The Reddish Prairie Soils are represented by Zaneis and Kingfisher (morphologically similar) Soils which are described as follows:

Zaneis Loam No. 2:

Location: 1520 ft east of southwest corner sec. 8, T. 19 N., R. 2 E., Payne County, Oklahoma. The area is a native tall grass prairie on normal erosional upland with weak convex surface and gradient of 2 per cent.

Horizon	Depth Inches	Description
A_1	0–11	Very dark reddish-gray (5YR 4/2; 3/2m) loam; moderate medium granular; porous; friable; roots abundant; pH 5.9; grades to horizon below.
B_1	11–23	Yellowish-red (5YR 4/8; 3/4m) clay loam; weak fine subangular blocky; friable; slightly hard; porous; roots abundant; pH 5.6; grades to horizon below.
B_{2-1}	23–32	Yellowish-red (5YR 5/6; 3/4m) clay loam; moderate fine subangular blocky; firm; hard; pH 5.7; sample boundary.
B_{2-2}	32–42	Same color as above clay loam; structure and consistence same as above; few ferruginous concretions; pH 5.8; grades to horizon below.
B_{3-1}	42–48	Yellowish-red (5YR 5/6; 4/6m) clay loam; strata of soft weathered sandstone; more ferruginous concretion than above; weak medium subangular blocky; firm; hard; pH 5.9; gradual wavy boundary to layer below.
B_{3-2}	48–58	Dark red (2.5YR 3/6) loam; weak subangular blocky; friable; slightly hard; ferruginous concretions increase with depth; some stratified layers of rather slightly weathered shale and sandstone; pH 6.2; very gradual boundary to parent material.
C	58–78	Dark reddish-brown (2.5YR 4/4; 3/4m) weathered sandstone and shale; pH 6.5.

The soil parent materials originated from the weathering of these bedded sandstones and shales of the Chase group of the Wellington formation.

Kingfisher Silt Loam No. 2:

Location: At E ¼ corner sec. 36, T. 13 N., R. SW., ½ mile west of Okarche. Site is in a native pasture which consists mostly of short and mid grasses; gradient is 1½ per cent, weak convex.

Horizon	Depth Inches	Description
A_{1-1}	0–7	Reddish-brown (5YR 4/4; 3/4m) silt loam, moderate medium granular; friable; permeable; pH 6.4; grades to horizon below.
A_{1-2}	7–14	Same as above except that structure is slightly stronger; pH 7.0; this grades through a 2-in. transition to the layer below.
A_3	14–19	Reddish-brown (5YR 4/4; 3/4m) silt loam; moderate medium granular; friable; numerous pores and fine root holes; pH 7.2; grades to the horizon below.
B_{2-1}	19–28	Reddish-brown (2YR 4/5; 3/5m) silty clay loam; moderate medium subangular blocky; firm; weak clay films on peds which are darker than interiors; pH 7.3; grades to the horizon below.
B_{2-2}	28–36	Reddish-brown (2.5YR 4/4; 3/4m) silty clay loam; compound coarse prismatic and weak medium blocky; firm; slowly permeable; pH 7.3; clay films apparent surfaces darker than interiors; grades to the layer below.
B_3	36–44	Red (2.5YR 4/6; 3/6m) silt loam much like layer above but without the clay films; a few black spots and partly weathered sandstone fragments; pH 7.3; grades to the layer below.
C_1	44–56	Red (2YR 4/8; 3/8m) heavy loam between seams of slightly hardened fine grained sandstone; slightly or indistinctly laminated with silty strata; pH 7.8; changes slightly to a less hard layer below.
C_2	56–68	Slightly hardened silty rocks; this rests on a thicker, hardened layer of sandstone at 68 in. which prohibits deeper digging; pH 8.2.

The parent material is weathered from the Cedar Hills sandstone a member of the Hennessey formation, Permian age.

The Prairie soils occupy a large portion of the landscape in eastern Oklahoma (1959). In some of these landscapes the Planosols occur in association with the Prairie soils. Both of these soils are developed in sedimentary rocks of Pennsylvanian Age. The Reddish Prairie soils occupy landscapes to the west which are dominantly underlain with sedimentary rocks of Permian Age. In this area the Reddish Prairie soils are associated with other Reddish Prairie soils which may be more sandy or more clayey depending upon the texture of the Permian Formations from which the soils developed. Also, in this area there is a noticeable absence of Planosol soils but an abundance of soils with "claypan" subsoils, such as the Kirkland soils.

By comparing the profile descriptions and chemical properties (Tables 2 and 3), the Prairie soils have profile characteristics which contrast markedly with the Planosols but differ to a much lesser degree with those of the Reddish Prairie. The Dennis soils have darker A_1 horizons than the Parsons, Zaneis or Kingfisher soils. The Parsons soils have light colored A_2 horizons. The Zaneis and Kingfisher soils have more reddish hues in the surface and throughout their profiles. The organic matter is slightly higher in the Dennis than the Zaneis or Kingfisher. All soils decrease gradually in organic matter

TABLE 2.—CHEMICAL MEASUREMENTS OF DENNIS AND PARSONS PROFILES

Field Horizon Designation	Depth in.	pH	% Organic Matter	Exchangeable Cations (meq per 100 g soil)						% Base Saturation
				Ca	Mg	K	Na	H	Sum	
				Dennis (*Wagoner County*)						
A_1	0–12	5.4	2.54	7.3	2.7	0.2	0.2	7.8	18.2	57
A_3	12–16	5.4	1.94	7.5	2.8	0.2	0.4	7.6	18.5	59
B_1	16–26	5.6	1.27	9.0	3.1	0.3	0.6	7.6	20.6	63
B_2	26–31	5.8	0.84	11.4	4.6	0.3	1.0	7.9	25.2	69
B_3	31–40	5.9	0.53	12.4	5.0	0.3	1.1	7.1	25.9	72
C_1	40–54	6.3	0.31	14.5	5.8	0.4	1.4	6.0	28.1	79
C_2	54–72	6.6	0.29	14.6	6.6	0.3	1.4	4.5	27.4	84
C_3	72–90	6.6	0.12	12.9	6.2	0.3	1.3	3.7	24.4	85
				Parsons (*Mayes County*)						
A_{1-1}	0–6	5.7	1.98	5.8	0.8	0.1	0.1	6.3	13.0	52
A_{1-2}	6–10	5.2	1.08	2.9	0.8	0.1	0.4	7.0	11.2	38
A_{2-1}	10–14	5.5	0.65	2.4	0.8	0.2	0.5	6.2	10.1	39
A_{2-2}	14–16	5.6	0.86	4.8	2.3	0.3	1.3	8.6	17.3	50
B_{2-1}	16–22	5.4	1.50	12.5	5.9	0.5	3.4	16.2	38.5	58
B_{2-2}	22–28	5.3	1.25	14.1	6.8	0.4	3.8	12.2	37.3	67
B_{3-1}	28–37	5.3	0.55	12.0	6.2	0.4	3.3	9.6	31.5	70
B_{3-1}	37–43	5.4	0.29	9.6	4.8	0.4	2.6	5.2	22.6	77
C_1	43–66	5.4	0.19	9.7	4.8	0.4	2.3	6.2	23.4	74
C_2	66–84	5.6	0.10	12.6	6.1	0.4	2.5	5.8	27.4	79

with depth except the Parsons which exhibits two maxima in organic matter content, with the second occurring at the 16–22 in. depth. Soil structures are quite similar in the surfaces for all the soils; however, the B_2 horizons of the Parsons are coarse blocky as compared to medium subangular blocky for the other soils.

The Parsons soils have lower pH, less exchangeable calcium, more exchangeable hydrogen, and lower base saturation than the other soils. The Dennis and Zaneis have similar pH, but the Zaneis has a higher base saturation percentage throughout the profile. The Kingfisher has higher pH values and higher base saturations than any of the soils that were studied. The soils in the order of leaching, weathering, and degree of development can be arranged with Parsons first followed by Dennis, then Zaneis with Kingfisher the least.

CLAY MINERALOGY

To more fully characterize the parent materials and related soils in central and northeastern Oklahoma, various clay mineralogical analyses were made on *A*, *B*, and *C* horizons of each soil studied except for the Kirkland 1 and 2 and Dennis 2 where only *B* and *C* horizons were studied.

All soils have more clay in the *B* horizon than in the *A* horizon or *C* horizon

TABLE 3.—CHEMICAL MEASUREMENTS OF THE ZANEIS NO. 2 AND KINGFISHER NO. 2 PROFILES

Horizon	Depth in.	pH with 1:1 Soil–water Ratio	% Organic Matter	CEC Meq/100 g	Exchangeable Cations Meq/100 g				% Base Saturation
					Ca	Mg	K	Na	
			Zaneis No. 2 (Payne County)						
A_1	0–11	5.9	2.50	11.5	4.8	3.2	0.4	0.3	75.7
B_1	11–23	5.6	1.50	16.1	6.6	4.4	0.3	0.4	72.7
B_{2-1}	23–32	5.7	1.22	15.9	6.6	5.1	0.4	0.6	80.0
B_{2-2}	32–42	5.8	0.71	14.0	6.0	5.7	0.3	0.6	90.0
B_{3-1}	42–48	5.9	0.42	14.3	6.1	5.7	0.3	0.6	88.8
B_{3-2}	48–58	6.2	0.17	13.5	6.4	6.7	0.3	0.6	100.0
C	58–78	6.4	0.07	11.4	5.4	5.1	0.3	0.6	100.0
			Kingfisher No. 2 (Kingfisher County)						
A_{1-1}	0–7	6.4	2.05	9.6	6.0	3.0	0.8	0.4	100.0
A_{1-2}	7–14	7.0	1.50	11.2	7.7	4.0	0.7	0.5	100.0
A_3	14–19	7.2	1.27	11.8	8.3	5.4	0.5	0.3	100.0
B_{2-1}	19–28	7.3	0.97	16.6	10.9	6.2	0.5	0.7	100.0
B_{2-2}	28–36	7.3	0.85	17.3	10.9	7.0	0.5	0.6	100.0
B_3	36–44	7.3	0.45	13.2	8.3	7.2	0.4	1.1	100.0
C_1	44–56	7.8	0.37	8.4	4.3	6.5	0.3	2.3	100.0
C_2	56–68	8.2	0.15	9.1	12.2	9.2	0.3	3.5	100.0

with the exception of Parsons and Kirkland whose clay contents of their *C* horizons were about equal to those of the *B* horizons.

However, the fine clay, which was measured to be the major component of the clay fraction (Tables 4 and 5) in soils developed in both Pennsylvanian and Permian formations, was not only found to be present in larger percentages in the *B* than *A* but also higher in the *B* than in the *C* horizons with few exceptions.

The mineralogical data for the Parsons and Dennis No. 1 profiles (Fanning and Gray, 1959) are presented in Table 4. The 10 per cent K_2O value for pure illite (Jackson *et al.*, 1954) was used to estimate the illite content of the two profiles. Using this criterion, it was concluded that illite is the dominant clay mineral of the coarse clay fraction of both profiles. The results obtained from the X-ray analysis, cation exchange capacities, and surface area measurements, indicates that montmorillonite dominates the fine clay fractions of both profiles. The fine clay fraction of the Dennis No. 1 profile has a somewhat higher percentage of K_2O, indicating more illite than is present in the Parsons. This, and the fact that there is a higher percentage of coarse clay in the Dennis, led to the conclusion that illite is the dominant mineral present in the Dennis while montmorillonite dominates the Parsons profile. The continuous decrease of coarse clay in the Dennis profile (as one moves upward from the parent material) along with a corresponding decrease in surface area of the fine clays led to the conclusion that there has been weathering of the coarse

TABLE 4.—IDENTIFYING CRITERIA FOR CLAY MINERALS OF THE PARSONS AND DENNIS NO. 1 PROFILES

Horizon	Per cent of Each Fraction	Clay Surface Areas*					DTA
		CEC Meq/100 g	K_2O %	Total m^2/g	Internal m^2/g	X-ray analysis	
		PARSONS					
		Coarse clay 2–0.1 microns					
A_{1-1}	1.4	13.2	4.2	49	21	Hm(K Q M)†	K
B_{2-1}	13.4	23.4	4.2	151	14	K(Q M)	K M
C_2	4.4	16.8	2.6	85	23	K(I Q M)	K
		Fine clay <0.1 micron					
A_{1-1}	10.8	53.7	1.6	404	281	M	M K
B_{2-1}	44.4	52.4	1.6	367	213	M	M K
C_2	35.4	52.7	3.1	344	221	M(I K)	M K
		DENNIS No. 1					
		Coarse clay 2–0.1 microns					
A_1	4.5	14.7	4.6	61	30	K(I Q M)†	K
B_2	12.7	16.7	4.6	75	34	K(I Q M)	K
C_3	23.2	15.4	5.0	69	33	K(I Q M)	K
Mont.‡	—	68.0	—	502	408	—	—
Illite‡	—	22.2	7.5	176	77	—	—
		Fine clay <0.1 micron					
A_1	15.3	53.2	2.4	258	157	M(K M/I)	M(K)
B_2	30.2	51.5	1.8	241	168	M(V K)	M K
C_3	13.4	53.1	1.7	357	219	M(H K)	M K
Mont.‡	—	75.4	—	557	504	—	—
Illite‡	—	27.5	6.8	215	38	—	—

* Measured by ethylene glycol retention.

† M—Montmorillonite, K—Kaolinite, I—Illite, Q—Quartz, Hm—Hydrous micas, H—Halloysite, V—Vermiculite, M/I—Mixed-layered minerals.

Dominant minerals present are outside parentheses. Other minerals present are enclosed by parentheses.

‡ Reference minerals are Wyoming bentonite and illite from near Fithian, Illinois.

clay particles into particles of fine clay size. This trend is not apparent in the Parsons profile. The mineralogical data obtained from the Parsons profile are quite uniform from horizon to horizon, giving very little indication of extensive weathering. In light of the uniformity of the over-all mineralogical properties, it appears that the clay minerals present in the solum *A* and *B* horizons, are inherited directly from the clay minerals present in the parent material, *C* horizons, in the Dennis profile as well as the Parsons profile, and clay mineral weathering has had little effect on the clay composition of the profile.

Wilkinson and Gray (1954) used non-exchangeable K and internal ethylene glycol retention values to estimate the relative amounts of montmorillonite and illite present in the Kirkland 1 and 2 and Dennis No. 2 profiles.

TABLE 5.—CLAY PROPERTIES OF THE DENNIS NO. 2 AND KIRKLAND PROFILES

Soil Horizon	Sampling Depth in.	Per cent of Each Fraction	Cation Exchange Capacity meq/100 g	% K_2O	Ethylene Glycol Retention mg/g	
					Internal	Total
		Dennis No. 2				
		Coarse clay 2–0.1 microns				
B	24	15.2	31.5	2.07	72	89
C	54	16.2	31.2	1.96	50	71
		Fine clay <0.1 micron				
B	24	26.9	57.1	1.02	103	149
C	54	22.9	55.0	1.02	119	151
		Kirkland No. 1				
		Coarse clay 2–0.1 microns				
B_{2-1}	14	20.6	33.75	2.16	42	68
C_1	32	20.5	35.00	2.26	66	89
		Fine clay <0.1 micron				
B_{2-1}	14	26.6	54.2	0.90	88	147
C_1	32	18.2	54.5	1.78	91	125
		Kirkland No. 2				
		Coarse clay 2–0.1 microns				
B_{2-1}	16	13.6	32.2	2.0	50	72
C_1	42	24.2	33.0	2.2	57	87
		Fine clay <0.1 micron				
B_{2-1}	16	23.4	56.4	0.86	113	157
C_1	42	11.4	51.3	0.98	110	145
	Montmorillonite (Standard)	—	—	—	187	205

The 10 per cent K_2O value for pure illite was used and the internal ethylene glycol retention of the reference montmorillonite was used to represent 100 per cent montmorillonite. Using the data on Table 5 the montmorillonite and illite content were calculated relative to these values. As no X-ray analysis was made the remainder of the clay fraction was unknown, and the only check on these values was the cation exchange capacity. The inherent errors of this method are obvious, but it probably gives about as good an approximation as any other method for estimating soil clays. The results of this investigation indicated that montmorillonite is the dominant clay mineral of all three profiles, and that most of it is found in the fine clay fraction. Illite was found to be a major component of the coarse clays, with lesser amounts present in the fine clays. Data are insufficient to reach any definite conclusion about weathering. However, judging by the uniformity of data between horizons of the same profile, it could seem that the clay minerals present in the *B* horizon are quite similar to those present in the *C* horizon.

The mineralogical data for the four Zaneis and two Kingfisher profiles (Molthan, 1960) are presented in Table 6. Per cent K_2O was used as an index of illite and glycol retention and cation exchange capacities as an index to

TABLE 6.—IDENTIFYING CRITERIA FOR CLAY MINERALS OF THE FOUR ZANEIS AND TWO KINGFISHER PROFILES

Horizon	% clay <2 micron	Coarse clay 2.0–0.2 microns					Fine clay <0.2 micron				
		CEC meq/100 g	% K_2O	mg/g Glycol Retent.	X-ray Analysis	DTA	CEC meq/100 g	% K_2O	mg/g* Glycol Retent.	X-ray Analysis	DTA
							Zaneis No. 1				
A_1	17.6	25	2.5	80	I_2,K_2,Q_2,I_s?	K, V	65	1.7	192	I_2,K_2,I_s?†	K, Hm
B_2	35.0	33	2.8	102	M_2,I_2,K_2Q_3	K, M	78	1.3	235	K_2,I_s?	K, Hm
C	23.9	24	2.3	75	$K_2,I_2,V/C_2,Q_3$	K, V	63	1.6	210	I_2,K_2,I_s?	K, Hm
D	8.6	29	2.3	88	$K_2,I_2,V/C_2,Q_3$	K, V	59	1.9	177	I_2,K_2,I_s?	K, Hm
							Zaneis No. 2				
A_1	17.5	22	3.0	71	I_2,K_2,Q_3	K, V	56	1.9	188	I_2,K_2,I_s?	K, Hm
B_2	32.7	29	2.5	86	I_2,K_2,Q_3	K, V	56	1.8	163	I_2,K_2,I_s?	K, Hm
C	21.6	24	2.7	73	$I_2,K_2,V/C_2,Q_3$	K, V	58	2.0	182	I_2,K_2,I_s?	K, V
							Zaneis No. 3				
A_1	15.6	30	2.7	82	$I_2,K_2,Q_3,V/C$?	K, V	61	1.9	187	I_2,K_2,I_s?	K, Hm
B_2	28.2	39	2.7	108	$I_2,K_2.Q_3,V/C$?	K, V	82	1.6	214	I_2,K_2,I_s?	K, Hm
C	25.3	37	3.1	88	$I_2,K_2,Q_3,V/C$?	K, V	71	2.0	206	I_2,K_2,I_s?	K, Hm
							Zaneis No. 4				
A_1	15.9	21	2.7	58	I_2,K_2,Q_2,I_s?	K, V	70	2.2	209	I_2,K_2,I_s?	K, Hm
B_2	32.8	48	3.0	111	$M/C_2,I_2,K_3,Q_3$	M, K	106	1.3	137	$M/C_2,I_2,K_3$	M, K
C	21.3	32	3.1	78	$I_2,K_2,V/C_2,Q_3$	K, V	72	1.8	192	I_2,K_2,I_s?	K, Hm
							Kingfisher No. 1				
A_1	19.7	21	4.5	63	I_2,K_2,Q_2,I_s?	V, K	72	2.7	210	I_2,K_3,I_s?	V, K
B_2	40.3	29	4.1	77	$I_2,K_2,Q_3,V/C$?	V, K	81	2.2	214	I_2,K_3,I_s?	V, K
C	25.0	37	3.7	100	$M/C_2,I_2,K_2,Q_3$	M, C, K	68	2.0	166	$M/C_2,I_2,K_2$	M, C, K
							Kingfisher No. 2				
A_1	12.9	21	4.5	64	I_1,K_2,Q_2,I_s?	V, K	66	3.5	186	I_1,I_s?	I, Hm
B_2	27.8	30	4.1	80	$I_1,K_2,Q_3,V/C$?	K, V	77	3.1	199	I_1,K_3,I_s?	I, K
C	16.7	31	4.2	92	$I_1,K_2,Q_3,V/C$?	V, K, C	65	3.9	198	I_2,K_3,I_s?	Hm, K

* Pure montmorillonite retains approximately 280 mg/g glycol.

† I—Illite, M—Montmorillonite, K—Kaolinite, V—Vermiculite, C—Chlorite, Q—Quartz, Is—Interstratified. Subscript refers to relative amount: 1—greater than 40 per cent, 2—10 to 40 per cent, 3—less than 10 per cent.

montmorillonite. X-ray diffraction analysis and DTA were used to determine the presence of other minerals and their relative amount. The interpretation of the X-ray analysis, data as interstratification, is due apparently to hydrated micas that are not uniformly hydrated. This was based on low angle scatter ($<8°2\theta$) for the Mg saturated, glycol solvated clay samples and a reduction of this scatter along with a significant increase of the 10Å peak when the samples were K saturated and heated. In light of the glycol retention values and cation exchange capacities, it appears that the bulk of this mineral is a high exchange, expanding lattice montmorillonitic type mineral. Using these identifying criteria, the result obtained in this investigation indicated that a montmorillonitic type mineral is the dominant clay mineral present in the fine clay fractions of all six profiles. The coarse clays show more diversity in properties with vermiculite, illite, kaolinite, and montmorillonite all being present as major components. Illite is the dominant clay mineral of the coarse clays, and is a major constituent of the fine clay fractions, of the two Kingfisher profiles. All four of the above-mentioned minerals are present in the Zaneis coarse clays along with some chlorite. No exact determination of the percentages of the two clay fractions were made; but from the results of the particle size separation, the relative amounts were fairly uniform throughout the profile with the fine clays dominating.

The results of this investigation gave little evidence of clay mineral weathering. The clay composition of the different horizons of most profiles is quite similar. This uniformity is reflected in the X-ray diffractogram as well as in the data presented in Table 6. The only notable exceptions to this are the Zaneis No. 4 and Kingfisher No. 1 profiles. In view of the data presented in Table 6, it would appear there has been a major alteration of minerals in these two profiles, but in light of other data, namely the mechanical analysis and location in the geological section, stratification of parent material appears to be a better answer to the apparent alteration. The unusually high cation exchange capacity and low glycol retention of the Zaneis No. 4 B_2 horizon cannot be explained at this time, except to note that the clay minerals are poorly crystallized.

CONCLUSIONS

The results of these investigations indicate that the clay composition of the soils studied is for the most part inherited from the clay minerals present in the parent material. Kunze *et al.* (1955) and Jarvis *et al.* (1959) studied related soils in Texas and Kansas, and reported this same type of situation and reached similar conclusions. Seemingly the clay minerals of these soils were formed during some previous weathering régime and laid down in the sedimentary parent material in a weathered state and are resistant to further weathering.

There are probably some minor alterations due to leaching and some change in particle size, but these appear to be limited in most of the profiles. The processes of eluviation and illuviation have rearranged the concentration of soil particles and changed the relative amounts of clay minerals, a good example of this is Zaneis No. 1 where there appears to be an accumulation of high exchange, expanding lattice mineral in the B_2 horizon, but the types of clay minerals present are fairly uniform throughout the profile.

Montmorillonite and illite are the dominant clay minerals present in these soils with lesser amounts of kaolinite and vermiculite. Montmorillonite is prominant in the fine clay fractions, and most of the kaolinite and vermiculite is restricted to the coarse clays. Illite tends to be a major component of both fractions, but is much higher in the coarse clays. The fine class are the major component of the clay fractions of most horizons, including the parent material.

The clay mineralogy is similar for Prairie, Planosol and Reddish Prairie soils in Oklahoma. The exception which requires more research is the Reddish Prairie soils which on the basis of Zaneis and Kingfisher data appear to contain more amorphous or less crystalline or more interstratified clays. This may also indicate that these soils are more youthful than the Planosols and the Prairie soils.

REFERENCES

Dyal, R. S., and Hendricks, S. B. (1950) Total surface of clays in polar liquids as a characteristic index: *Soil Sci.*, v.69, pp.421–423.

Fanning, C. D., and Gray, Fenton (1959) Characterization and genetic study of a Dennis and a Parsons soil: *Soil Sci. Soc. Amer. Proc.*, v.23, pp.321–324.

Gray, F., and Galloway, H. M. (1959) Soils of Oklahoma, Okla. Agric. Exp. Sta. MP 56.

Hall, W. T. (1937) *Textbook of Quantitative Analysis* (2nd ed.), pp.225–230, John Wiley, New York.

Jackson, M. L. (1958) *Soil Chemical Analysis*, Prentice-Hall, Englewood Cliffs, New Jersey.

Jackson, M. L., Whittig, L. D., Vandenttenvel, R. C., Kaufman, A., and Brown, B. E. (1954) Some analyses of soil montmorin, vermiculite, mica, chlorite, and interstratified layer silicates. *Clays and Clay Minerals*, Natl. Acad. Sci.–Natl. Res. Council, Pub. 327, pp.218–240.

Jackson, M. L., Whittig, L. D., and Pennington, R. P. (1949) Segregation procedure for the mineralogical analysis of soils: *Soil Sci. Soc. Amer. Proc.*, v.14, pp.77–81.

Jarvis, N. L., Ellis, R., and Bidwell, D. W. (1959) A chemical and mineralogical characterization of selected Brunizem, Reddish Prairie, Grumusol, and Planosol soils developed in Pre-Pleistocene materials: *Soil Sci. Soc. Amer. Proc.*, v.23, pp.234–239.

Kunze, G. W., Templin, E. H., and Page, J. B. (1955) The clay mineral composition of representative soils from five geological regions of Texas: *Clays and Clay Minerals*, Natl. Acad. Sci.—Natl. Res. Council, Pub. 395, pp.373–383.

Martin, R. T. (1955) Ethylene glycol retention by clays: *Soil Sci. Soc. Amer. Proc.*, v.19, pp.160–164.

Molthan, H. D. (1960) A chemical and mineralogical characterization and genesis study of the Zaneis and Kingfisher soil series of the Reddish Prairie great soil group. Master of Science thesis, Okla. State Univ.

Peech, M., Alexander, L. T., Dean, T. A., and Reed, J. F. (1947) Methods of soil analysis for soil fertility investigations: *U.S.D.A. Circ.* No. 757.

Schollenberger, C. J. (1931) Determination of organic matter: *Soil Sci.*, v.31, pp.483–496.

Steele, J. G., and Bradfield, R. (1943) The significance of size distribution in clay fractions: *Amer. Soil Survey Assoc., Bull.* 15, pp.89–93.

Whitt, D. M., and Baver, L. D. (1937) Particle size in relation to base exchange and hydrogen properties of Putnam clay: *J. Amer. Soc. Agron.*, v.29, pp.906–916.

Wilkinson, G. E., and Gray, Fenton (1954) A clay mineralogical study of certain Reddish Prairie soils of Oklahoma, with an estimation of the montmorillonite and illite content: *Soil Sci. Soc. Amer. Proc.*, v.18, pp.264–268.