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CLAY MINERALS IN SEDIMENTARY ROCKS AND DERIVED SOILS

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ABSTRACT. Analyses of 43 clay fraction samples from sedimentary rocks and their derived soils, together with a review of published studies of soils developed on sedimentary material, reveal: (1) Clay minerals in soils formed on sedimentary rocks commonly are inherited from parent material. Some of the kaolinite-rich soils of southeastern United States have inherited the clay mineral from Coastal Plain deposits; at least some of the montmorillonite in soils of the western Great Plains has been inherited from montmorillonite-rich parent rock; illite is a common mineral in soils developed on illite-rich Pleistocene glacial deposits and Paleozoic marine shale. (2) Because illite is abundant in many kinds of sedimentary materials, this clay mineral group is commonly the predominant type in soils formed on sedimentary bedrock. (3) Alluvium carried to depositional basins contains considerable illite eroded from widespread, illite-bearing soils. (4) The composition of modern illite-rich alluvium deposited in the sea has not been significantly altered by the marine environment. (5) The kind of illite common in soils and alluvium generally has a lower K_2O content and SiO_2/Al_2O_3 ratio than the illite in many sedimentary rocks, indicating that inherited illite generally has been altered somewhat by soil-forming processes.

INTRODUCTION

BECAUSE soils were the main source of the clay fraction of modern alluvium and marine deposits and of sedimentary rocks, the clay mineral composition of soils and the origin of these minerals are an important aspect of the study of sediments.

In most of the general discussions of soil composition the abundant clay minerals present are considered to be primary products of weathering, the kind produced being controlled mainly by environmental conditions. Minerals of the kaolinite group predominate in soils of warm, humid regions; minerals of the montmorillonite and illite[1] groups are prevalent in the soils of cooler or drier regions. Inasmuch as kaolinite and montmorillonite apparently are the more common authigenic clay mineral groups, it has generally been assumed that illite is rare in soils and that the alluvium carried to depositional basins contains essential proportions of kaolinite and montmorillonite (Ross, 1945, pp. 182-183).

[1] In older publications kaolinite and montmorillonite were considered to be the only clay mineral types in soils.

The belief that kaolinite and montmorillonite are the most abundant and widespread clay minerals in soils is no longer tenable. Since illite was first reported as the principal mineral in some soil colloids by Hendricks and Fry (1930) numerous examples of illite-rich soils have been described. In fact, present evidence indicates that, although long and intense weathering may alter the composition of illite, an illite-type mineral nevertheless occurs abundantly in the regolith. Recently accumulating evidence also invalidates the assumption that the clay in soils developed on sedimentary rock is predominantly of primary origin. It should be clear, however, that the clay in soils developed on igneous and metamorphic rocks must be primary.

In a few of the many detailed studies of soil composition the clay minerals have been interpreted as inherited from parent sedimentary rocks. The clay in the montmorillonite-rich White Store soil (41)[2] of North Carolina, for example, is believed to have been derived from the montmorillonite-rich Triassic shale on which the soil has formed. The Norfolk soils (27) of North Carolina are developed on Cenozoic sediments of the Atlantic Coastal Plain, and in the colloidal fraction of both the soil and parent material there is a molecular SiO_2/Al_2O_3 ratio of kaolinite. "It is perhaps reasonable to assume that the greater part of the clay content now present in these soils existed in the soil parent material at the time it was laid down" (Holmes, Hearn, and Byers, 1938, p. 27). Most of the clay in a number of illite-rich Solonetz and Black Alkali soils probably was inherited from parent alluvial deposits (Kelley, Dore, and Page, 1941, pp. 121, 123). Similarly, the abundance of kaolinite in the Gosport soil (13) of Iowa has been attributed to its kaolinite-rich parent Pennsylvanian shale, and a study of illite-bearing Miami and related soils (25) in Ohio led to the conclusion that these soils may have inherited much of their clay from their parent material, illite-bearing Late Wisconsin glacial drift. Numerous other recorded analyses, such as those of Iowa soils by Peterson (1946) and by Russell and Haddock (1941) and those of Minnesota soils by Caldwell and Rost (1942), reveal no appreciable change in colloidal composition or clay mineral content with depth in the profile of soils developed on sedimentary rocks.

[2] Soils with references listed by number in table 1.

Despite evidence of this sort, inherited clay minerals in soil have not been extensively investigated, nor has this mode of origin been recognized as an important factor in most discussions of soil composition. The possibility of the derivation of soil clay from clay-bearing sedimentary material is of particular significance when considered in light of the fact that about 75 per cent of the soil of the United States has developed on sedimentary deposits and that illite minerals are known to be abundant in most shales, marine sedimentary rocks and modern marine sediments, as well as in loess and glacial drift, and in some underclay and gumbotil (see Grim, Lamar, and Bradley, 1937; Grim, Bray, and Bradley, 1937; Hursh, Lamar, and Grim, 1944; Grim, Dietz, and Bradley, 1949; Grim, 1951; and Weaver and Bates, 1950).

If soils formed on the widespread mantle of sedimentary material can inherit their clay minerals and if these minerals are relatively stable, then illite should occur more commonly in soils than is generally suggested in the literature, and it should be among the more common clay minerals carried by streams to depositional basins. The present study is an investigation of these possibilities by (A) assembling and discussing some of the many recorded analyses of soils and parent sedimentary material that bear on this problem, and by (B) determining the predominant clay minerals present in a varied collection of soils and their parent sedimentary rocks. This project has been supported by a research contract between the Office of Naval Research and Princeton University (contract N8onr-73800). The Department of Geology, Princeton University, generously provided transportation and laboratory facilities. The help of M. Lougheed, Wm. Poole, A. Sutherland-Brown, and Wm. Yahn as research assistants is gratefully acknowledged. It is a pleasure to record my indebtedness to Professor A. F. Buddington for his continued interest and helpful advice throughout the course of this investigation.

A

In the following discussion of clay minerals in the colloidal fraction of soil profiles the C horizon is considered to be parent material not yet affected by soil-forming processes. Similarity of composition of A and C horizons is emphasized here, but this is not to deny that there is significant movement or frac-

tionation of colloidal material through the profile, or that clay minerals inherited from parent rock may be altered by appropriate weathering conditions (see Jackson, *et al.*, 1948). Furthermore, a soil colloid containing some inherited clay may be composed largely of primary clay minerals produced by weathering of detrital minerals of the parent rock. It is also recognized that the coarser and finer colloidal fractions generally contain different proportions of the clay minerals (Bray, 1934; Keller and Ting, 1950), and that few soil clays consist of a single clay mineral. Instead, most contain a complex mixture of very small units of several clay minerals, although one mineral commonly is dominant. In this discussion illite (illitic), montmorillonite (montmorillonoid), and kaolinite (kaolinic) refer to groups of clay minerals, not to particular minerals.

Intense weathering has converted montmorillonite in the Cenozoic deposits of the Alabama Coastal Plain to kaolinite in the overlying Susquehanna soil (39). The difference in clay content of the soil and parent material is clearly reflected in the molecular SiO_2/Al_2O_3 ratios of the A (2.73) and C (3.95) horizons—a 1.22 difference. In contrast to this example of an authigenic soil clay, the kaolinite-rich Decatur soil (17) and Norfolk soil (27) and the montmorillonite-rich Houston and related soils (18, 19, 9, 28) undoubtedly inherited their clay minerals from parent material. In these soils the same clay minerals predominate in the A and C horizons and there are similar SiO_2/Al_2O_3 ratios throughout each profile.

In many soils developed on sedimentary parent material illite is abundant in the A and C horizons (table 1; 6, 8, 12, 25, 26, 31, 36), or there are similar SiO_2/Al_2O_3 ratios throughout each profile (no difference exceeds 0.51) and illite has been identified as the dominant clay mineral[3] in the B horizons (table 1; 2, 3, 4, 5, 16, 17, 22, 24, 30, 37, 40). These data reveal that in many different kinds of soil widely distributed throughout the United States (fig. 1) illite is the abundant clay mineral and that much of it undoubtedly was derived from illite-rich parent material. Further suggestive evidence is provided by an illite-bearing Paleosol (29) in the Rocky Mountain region that developed on Paleozoic marine shale. Because illite is known to be abundant

[3] K-bentonite type clay mineral is considered to be an illite mineral (Weaver and Bates, 1950) or a mixed layer aggregate with layers of illite (Kerr, *et al.*, 1950*a* and *b*).

TABLE 1

Chemical Data and Clay Mineral Content of Colloidal Fraction of Soils and Sediments Discussed in Text

A. A horizon of soil
B. B horizon of soil
C. Parent material of C horizon

I — Illite group
M — Montmorillonite group
K — Kaolinite group

Soil		%K_2O	molecular SiO_2/Al_2O_3	Predominant clay mineral	Reference (Tech. Bulls. cited are of U. S. Dept. Agr.)
I Zonal and Intrazonal soils, Lithosols, and Palcosols					
1. Badland silt loam, Lithosol	A.	2.70	5.53		Tech. Bull. 502
Interior, Jackson Co., South Dakota	B.	2.72	5.37		This paper, table 2;5
Oligocene White River formation (non-marine)	C.	2.61	5.76	C. Illite and Montmorillonite	
2. Barnes loam, Chernozem soil	A.	1.70	4.07		Tech. Bull. 484
Labolt, Grant Co., South Dakota	B.	1.44	4.29	B. 40%I, 30%K, 20%M	Alexander, *et al.*, 1939
Wisconsin glacial drift (calcareous)	C.	1.40	4.41		
3. Bethel silt loam, Planosol	A.	1.31	3.63		Tech. Bull. 834
2.5 miles south of Green Fork, Wayne Co., Ind.	B.	1.10	3.40	B. 65%+I, 25%-M, 10%K	
Wisconsin glacial drift (calcareous)	C.	3.30	3.40		
4. Brookston silty clay loam, Half-bog soil	A.	2.62	3.41		Tech. Bull. 834
Fairmont, Grant Co., Ind.	B.	2.49	3.91	B. 65%I, 25%M, 10%K	Nelson and Hendricks, 1943
Late Wisconsin glacial drift	C.	4.86	3.27		
5. Carrington loam, Prairie Soil	A.	1.44	3.33		Tech. Bull. 484
Winthrop, Buchanan Co., Iowa	B.	1.85	3.17	B. 40%I, 40%K, 10%M	Alexander, *et al.*, 1939
Iowan glacial drift (calcareous)	C.	1.89	3.23		
6. Cayucos sandy clay loam, Prairie soil	A.	0.66	4.93	A. Illite	Barshad, 1946
Rodeo, Contra Costa Co., Calif.		.....	.....		
Unconsolidated non-calcareous sandstone	C.	0.94	5.25	C. Illite	
7. Decatur clay loam, Red and Yellow Podzolic soil	A.	1.24	2.27		Alexander, *et al.*, 1939
Russelville, Franklin Co., Ala.	B.	.88	2.12	B. 70%K, 10%I	Pearson and Ensminger, 1949
Paleozoic massive limestone (marine)	C.	.68	2.02	C. Kaolinite	
8. Dodgeville silt loam, Gray-Brown Podzolic soil		.....	.....	A. K-bentonite type, some Illite	Jackson, *et al.*, 1948
Southern Wisconsin					
Wisconsin glacial drift		.....	.....	C. Illite	
9. Eutaw clay, Rendzina		.....	.....	A. M and K	Pearson and Ensminger, 1949
Black belt, central Ala.		.....	.....		
Upper Cretaceous marine deposits		.....	.....	C. M and K	
10. Frederick silt loam, Gray-Brown Podzolic soil	A.	1.00	2.24		Tech. Bull. 678
Rockbridge Co., Va.	B.	1.22	2.10	B. 70%K, 10%I	Alexander, *et al.*, 1939
Paleozoic limestone and shale (marine)	C.	1.24	2.10		
11. Fullerton gravelly loam, Red and Yellow Podzolic soil	A.	0.86	3.07		Tech Bull. 678
Lawrence, Cherokee Co., Ala.	B.	1.28	3.11	B. 60%K, 20%I	Alexander, *et al.*, 1939
Paleozoic cherty limestone (marine)	C.	1.48	2.61		
12. Gleason clay loam, Prairie soil		.....	3.77	A. Illite	Barshad, 1946
12 miles northeast of Alturas, Modoc Co., Calif.		.....	.....		
Cenozoic acid andesite tuff (non-marine)		.....	3.59	C. Illite	
13. Gosport silty clay loam, Gray-Brown Podzolic soil		.....	.....	A. Kaolinite	Peterson, 1946
Marion Co., Iowa		.....	.....		
Pennsylvanian Des Moines shale		.....	.....	C. Kaolinite	
14. Hagerstown silty clay loam, Gray-Brown Podzolic soil	A.	1.00	2.19		Tech. Bull. 678
Center Co., Penn.	B.	1.45	2.16	B. 70%K, 20%I	Alexander, *et al.*, 1939
Paleozoic massive limestone (marine)	C.	1.24	2.17		
15. Hagerstown silt loam, Gray-Brown Podzolic soil	A.	1.51	2.33		Tech. Bull. 678
Hagerstown, Washington Co., Md.	B.	2.30	2.44	B. 50%K, 40%I	Alexander, *et al.*, 1939
Paleozoic massive limestone (marine)	C.	2.30	2.45		
16. Hays silty clay loam, Chernozem soil	A.	2.30	4.25		Tech. Bull. 502
1 mile south of Hays, Ellis Co., Kan.	B.	2.11	4.29	B. K-bentonite type	Tech. Bull. 316
Upper Cretaceous Carlisle shale (marine)	C.	2.11	4.37		
17. Hillsdale fine sandy loam, Gray-Brown Podzolic soil	A.	1.95	3.02		Tech. Bull. 834
Ingham Co., Michigan	B.	2.58	2.94	B. 75%I, 10%K, 10%M	Nelson and Hendricks, 1943
Late Wisconsin glacial drift	C.	3.41	3.07		
18. Houston black clay, Rendzina	A.	1.13	3.90	A. Montmorillonite	Hendricks and Fry, 1930
2 miles south of Temple, Bell Co., Texas	B.	.99	3.91		Tech. Bull. 316
Upper Cretaceous Taylor marl (marine)	C.	1.07	3.97		
19. Houston clay, Rendzina		.....	.....	A. M and K	Pearson and Ensminger, 1949
Black belt, central Ala.		.....	.....		
Upper Cretaceous Selma chalk (marine)		.....	.....	C. M and K	
20. Keith silt loam, Chestnut soil	A.	2.42	4.61		Tech. Bull. 502
Dundy Co., Nebraska	B.	2.16	4.53		Swineford and Frye, 1951
Pleistocene Peorian loess (non-marine)	C.	2.21	4.52	C. M and I?	
21. Lebanon silt loam, Red and Yellow Podzolic soil	A.	1.48	3.38		Tech. Bull. 678
St. James, Phelp Co., Mo.	B.	1.29	3.29		
Paleozoic cherty limestone (marine)	C.	0.79	2.70		
22. Marshall silt loam, Prairie soil	A.	2.14	3.69		Tech. Bull. 316
9 miles west of Clarinda, Page Co., Iowa	B.	1.58	3.72	B. K-bentonite type	
Pleistocene loess (non-marine)	C.	1.69	3.57		
23. Maury silt loam, Red and Yellow Podzolic soil	A.	1.90	2.58		Tech. Bull. 678
Ashwood, Maury Co., Tenn.	B.	2.42	2.11		This paper, table 2; 30 and 31
Paleozoic phosphatic limestone (marine)	C.	3.93	3.24		
24. Miami soil, Gray-Brown Podzolic soil	A.	2.42	3.23		Tech. Bull. 834
Williamsburg, Wayne Co., Ind.	B.	2.44	3.17	B. 65%+I, 25%-M, 10%K	
Late Wisconsin glacial drift (calcareous)	C.	3.56	3.21		
25. Miami soil, Gray-Brown Podzolic soil		.....	.....	A. Illite	Bidwell and Page, 1951
Clark Co., Ohio		.....	.....		
Late Wisconsin glacial drift		.....	.....	C. Illite	
26. Mifflinburg soil, Gray-Brown Podzolic soil		.....	.....	A. Illite and Chlorite	Jeffries and Yearick, 1949
Union Co., Penn.		.....	.....		
Pleistocene glacial drift		.....	.....	C. Illite and Chlorite	

TABLE 1 (*Cont.*)

Chemical Data and Clay Mineral Content of Colloidal Fraction of Soils and Sediments Discussed in Text

A. A horizon of soil
B. B horizon of soil
C. Parent material of C horizon

I — Illite group
M — Montmorillonite group
K — Kaolinite group

Soil	%K_2O	molecular SiO_2/Al_2O_3	Predominant clay mineral	Reference (Tech. Bulls. cited are of U. S. Dept. Agr.)
27. Norfolk soil, Red and Yellow Podzolic soil	A. 0.52	A. 1.90	A. Kaolinite	Tech. Bull. 594
eastern North Carolina, Georgia, and Alabama	B. 0.53	B. 1.86		Pearson and Ensminger, 1949
Cenozoic deposits of Atlantic and Gulf coastal plains	C. 0.30	C. 1.93	C. Kaolinite	
28. Oktibbeha clay, Rendzina	.....	.....	A. M and K	Pearson and Ensminger, 1949
Black belt, central Ala.	.....	.....		
Upper Cretaceous marine deposits	.....	.....	C. M and K	
29. Paleosol, Pre-Wisconsin age	.....	A. 7.22	A. Illite	Hunt and Sokoloff, 1950
Provo Canyon, Utah	.....	.....		
Upper Paleozoic Manning Canyon shale (marine)	.....	.....	C. Illite?	
30. Palouse silt loam, Chernozem soil	A. 2.12	A. 3.23		Tech. Bull. 316
3 miles northwest of Pullman, Whitman Co., Wash.	B. 1.64	B. 3.24	B. K-bentonite type	
Pleistocene loess (non-marine)	C. 1.46	C. 3.50		
31. Pawnee silt loam, Prairie soil	.....	.....	A. Illite, in coarse clay fraction	Larson, *et al.*, 1947
Gage Co., Nebraska	.....	.....		
Kansan glacial till	.....	.....	C. Illite, in coarse clay fraction	
32. Pierre clay, Lithosol	A. 2.14	A. 3.76		Tech. Bull. 502
Gregory Co., South Dakota	B. 2.14	B. 3.93		
Upper Cretaceous Pierre shale (marine)	C. 2.15	C. 4.01		
33. Pullman loam, Reddish Chestnut soil	A. 2.68	A. 3.89		Tech. Bull. 502
Masterson, Nash Co., Texas	B. 2.50	B. 3.87		
Pliocene Ogallala formation (non-marine)	C. 2.26	C. 3.37		
34. Putnam silt loam, Planosol	A. 0.94	A. 3.86	A. Mixed layer aggregate or beidellite	Ross and Hendricks, 1945
northeastern Missouri	.....	.....		
Pleistocene loess (non-marine)	.....	.....	C. M and I?	
35. Scobey loam, Chestnut soil	A. 2.35	A. 4.47		Tech. Bull. 502
McKensie Co., North Dakota	B. 1.90	B. 3.97		
Wisconsin glacial drift (calcareous)	C. 1.80	C. 4.34		
36. Scott silt loam, Wiesenboden soil	.....	.....	A. Illite, in coarse clay fraction	Larson, *et al.*, 1947
Saunders Co., Nebraska	.....	.....		
Pleistocene loess (non-marine)	.....	.....	C. Illite, in coarse clay fraction	
37. Shelby silt loam, Planosol	A. 1.19	A. 3.31		Tech. Bull. 316
6 miles west of Bethany, Harrison Co., Mo.	B. 1.62	B. 3.57	B. K-bentonite type	
Kansan glacial drift	C. 1.66	C. 3.54		
38. Spearfish silt loam, Lithosol	A. 2.33	A. 3.35		Tech. Bull. 502
Piedmont, Mead Co., South Dakota	B. 4.07	B. 3.06		Van Houten, 1948
Triassic Spearfish formation	C. 4.65	C. 2.97	C. Illite	
39. Susquehanna soil, Red and Yellow Podzolic soil	A. 0.34	A. 2.73	A. Kaolinite	Kelley, *et al.*, 1939
23 miles southeast of Montgomery, Montgomery Co., Ala.	.....	.....		Pearson and Ensminger, 1949
Cretaceous deposits, Gulf Coastal Plain (marine)	C. 0.26	C. 3.95	C. Montmorillonite	
40. Vernon sandy loam, Reddish Prairie soil	A. 2.13	A. 3.45		Tech. Bull. 316
4 miles south of Guthrie, Logan Co., Okla.	B. 2.34	B. 2.94	B. K-bentonite type	
Permo-Triassic red beds	C. 2.41	C. 2.94		
41. White Store Soil, Red and Yellow Podzolic soil	.....	.....	A. Montmorillonite	Ross and Hendricks, 1945
eastern Triassic basin, N. Carolina	.....	.....		
Triassic shale and sandstone (non-marine)	.....	.....	C. Montmorillonite	
II Sediments and Alluvial Soils (little or no profile)				
42. Red and sandy silt; Little Colorado River, Arizona	2.44	4.45	I, M, and K in equal amounts	Grim, *et al.*, 1949
43. Gray silt; center Mission Bay, San Diego, Calif.	2.39	3.81	I, M, and K in equal amounts	Grim, *et al.*, 1949
44. Green mud; west of Gulf of California	2.97	4.81	40%±I, 30%±M, 20%±K	Grim, *et al.*, 1949
45. Green silty clay; about 6 miles west of Pacific coast, northwest of San Diego, Calif., 275 fms.	2.69	4.00	40%±I, 30%±M, 20%±K	Grim, *et al.*, 1949
46. Mud from continental slope, about 175 miles west of San Diego, Calif., 1717 fms.	2.50	5.78	40%±I, 30%±M, 20%±K	Grim, *et al.*, 1949
47. Huntington loam, Alluvial soil; 3 miles northeast of Goconda, Ill., in Livingston Co., Ky.	3.40	2.78	70%I, 15%K, 10%M	Tech. Bull. 883
48. Huntington silt loam, Alluvial soil; Smithland, Livingston Co., Ky.	2.81	2.90	70%I, 10%K, 10%M	Tech. Bull. 883
49. Sharkey silty clay loam, Alluvial soil; 6 miles south of Onward, Route 61, Sharkey Co., Miss.	2.74	3.79	50%I, 35%M, 10%K	Tech. Bull. 883
50. Wabash silt loam, Alluvial soil; New Albin, Allamakee Co., Iowa	1.51	4.32	50%I, 35%M, 10%K	Tech. Bull. 883
51. Harve silty clay loam, Alluvial soil; Yellowstone River Bridge, Richland Co., Mont.	2.64	3.67	50%I, 35%M, 15%K	Tech. Bull. 883
52. Miller clay, Alluvial soil; Alexandria, Rapides Parish, La.	3.15	3.70	60%I, 20%M, 15%K	Tech. Bull. 883
53. Bibb silt loam, Alluvial soil; 9 miles southwest of Bastrop, Morehouse Parish, La.	1.85	3.22	70%I, 15%K, 10%M	Tech. Bull. 883
54. Sediment, Mississippi River mouth, Burrwood, Plaquemines Parish, La.	2.44	4.08		Tech. Bull. 883
55. Sediment, 3 miles southeast of Mississippi Delta, 70 fms.	2.62	3.78		Tech. Bull. 883
56. Sediment, Gulf of Mexico, two-thirds distance from delta to Florida, 1770 fms.	2.48	4.42		Tech. Bull. 883

in such shale, it is reasonable to conclude that the illite in the Paleosol may have been inherited from an illite-rich parent rock.

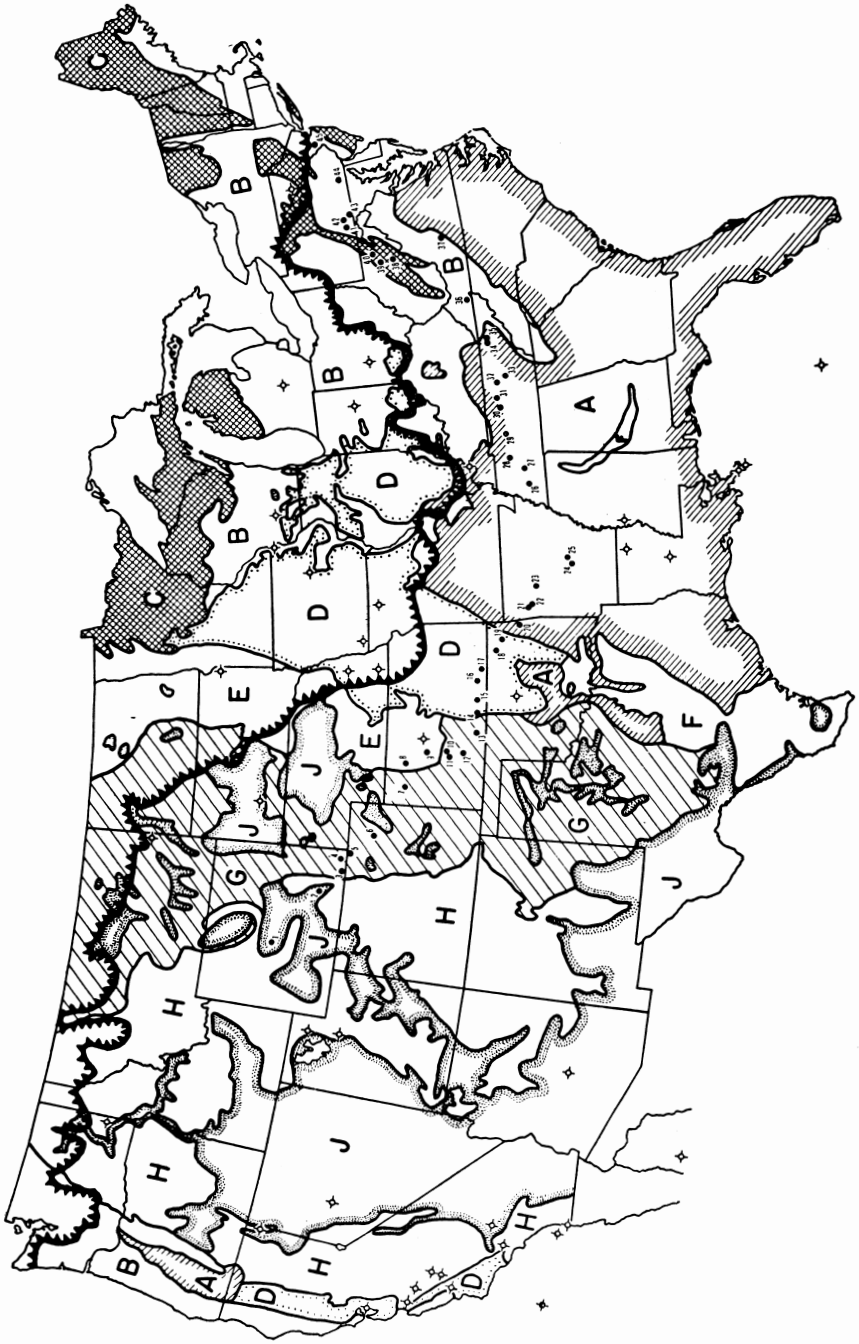
In addition to the persistently high SiO_2/Al_2O_3 ratios in the profiles of illite-bearing soils, the K_2O content of their soil colloids is, with but few exceptions, higher than in soil colloids rich in kaolinite and montmorillonite minerals.[4] Moreover, the K_2O content of many of these soils is remarkably like that of illite-rich sediments in the Pacific Ocean and Gulf of California (table 1; 43-46; also fig. 3; A, B, E, F). The amount commonly present (1 to 4 per cent) is, however, less than in Fithian[5] illite (table 3; d). In fact, the illite-rich Cayucos soil colloid (6) contains as little as 0.66 per cent K_2O, and Ross and Hendricks (1945, p. 61) have concluded that the presence of 0.94 per cent K_2O in the Putnam soil (34) reveals that its clay mineral may be a mixed layer aggregate with layers of illite.[6] Apparently more than 1 per cent K_2O in the colloidal fraction is suggestive evidence of the presence of some illite or illite layers in a mixed layer mineral. Hendricks and Fry (1930) first pointed out that the kind of illite in soil colloids contains less K_2O than the illite in Ordovician K-bentonite. More recent work has shown that the illite mineral abundant in soils is a degraded form produced during weathering by the leaching of some K^+ from between the silicate layers (Grim, 1951). The fact that in some of the illite-bearing profiles recorded in table 1 (3, 4, 17, 24) the K_2O content of the A horizon colloidal fraction is appreciably less than that of the parent material may be evidence of the process in operation. The presence of a degraded form of illite in soil must be recognized in attempts to estimate the illite content from chemical data. Several published estimates have been made assuming a 4 to 6 per cent K_2O content, and as a result the proportion of illite reported probably is too small.

The kind of clay minerals present in the colloidal fractions of the Keith (20), Pullman (33), Scobey (35), and Spearfish (38) soil profiles have not been reported in the literature referred to. The molecular SiO_2/Al_2O_3 ratios and K_2O contents

[4] In early studies of soils a high potassium content of the colloids was attributed to the presence of unweathered feldspar.

[5] Illite from Pennsylvanian underclay at Fithian, Illinois, is a representative example of illite as defined by Grim, Bray, and Bradley, 1937.

[6] The whole colloid of the Putnam soil of Illinois contains 1.74 per cent K_2O, according to Bray, 1934.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show little variation throughout the profiles and are similar to those of many illite-rich soil colloids. Moreover, illite is the predominant clay mineral in analyzed samples of the Spearfish formation (Van Houten, 1948, p. 2100) and the other soils are developed on sedimentary materials in which illite commonly is abundant. The evidence strongly suggests that these soils may contain inherited illite. But chemical composition generally is not a reliable guide for the prediction of the clay minerals present, especially since the colloid may contain some uncombined silica or alumina and a montmorillonite clay mineral with adsorbed K^+ may have a composition much like degraded illite. In fact, the SiO_2/Al_2O_3 ratios of these profiles are not unlike that of montmorillonite (table 3; f and g), and this clay mineral has been reported (Ross and Hendricks, 1945, p. 63) to be a prominent constituent of northern Prairie and Chernozem soils developed on calcareous glacial drift and loess (cf. Keith and Scobey soils). However, Ross and Hendricks do suggest that the clay in these soils is partly inherited from parent material. Montmorillonite may also be the predominant clay mineral in the Pierre shale (Grim, 1951, p. 228) parent rock of the Pierre soil (32).

A number of reported montmorillonite-rich soils are based on the identification of beidellite in colloidal fractions containing more than 1 per cent K_2O. It is significant, therefore, that some of the clay minerals that have been called beidellite actually are a mixture in which illite is an important component

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Fig. 1. Generalized map of great soil groups of United States.

- A. Red and Yellow Podzolic soils
- B. Gray-Brown Podzolic soils
- C. Podzolic soils
- D. Prairie and Reddish Prairie soils, and Planosols
- E. Chernozem soils
- F. Rendzina soils
- G. Brown, Reddish Brown, Chestnut, and Reddish Chestnut soils
- H. Undifferentiated mountain soils, and complex areas of soils in California
- J. Gray Desert and Red Desert soils, and Lithosols

Barbed line, southern limit of Pleistocene glacial drift sheets.

Circle with cross, illite-rich soils and sediments recorded in literature (table 1).

Solid circle, soils and parent rock analyzed in this investigation (table 2).

(Grim and Rowland, 1942, p. 801-804; Grim, Dietz, and Bradley, 1949, p. 1788). Loess, for example, has been described as containing abundant beidellite, but at least some of it is composed predominantly of illite (Hursh, Lamar, and Grim, 1944, p. 22) and the colloidal fraction of loess-derived soils of Illinois contains a mixture of illite and montmorillonite (beidellite) (Grim, 1941, p. 13; Kurtz, DeTurk, and Bray, 1946, p. 114). The Putnam soil of northeastern Missouri (table 3; k) has been reported as beidellite-rich, but it may, instead, contain a mixed layer mineral with layers of illite. Similarly, Kerr, *et al.* (1950*a*, p. 39) have shown that several clays reported to be beidellite are illite and montmorillonite mixed layer aggregates. In fact, in pointing out the common occurrence of mixed layer minerals, Hendricks and Alexander (1939, p. 261) expressed doubt that individual montmorillonite crystals are even common constituents of soils and concluded that much of the clay fraction of soils and sediments apparently is an intricate mixture of several clay minerals. Identification of these clay minerals is made still more difficult by the fact that some minerals of the montmorillonite and illite groups may have very similar physical properties (Weaver and Bates, 1951).

An analysis of alluvial[7] soils of the Mississippi drainage basin by Holmes and Hearn (1942) has revealed that the colloidal fractions of eastern tributary soils have consistently lower molecular SiO_2/Al_2O_3 ratios than do the colloidal fractions of western tributary alluvial soils. But the eastern alluvial soils have the highest average illite and K_2O content. The data in table 1 show similarly that the colloidal fractions of the uniform zonal[8] soil profiles in areas drained by eastern tributaries (table 1; 3, 4, 17, 24) have lower SiO_2/Al_2O_3 ratios than those of soil profiles in areas drained by western Mississippi tributaries (table 1; 2, 5, 16, 22, 37, 40; table 2; 13, 14, 17). Comparative data are assembled in table 1a.

Because both zonal and alluvial soils in the east have low SiO_2/Al_2O_3 ratios and yet contain relatively as much or more illite than their western counterparts the low ratio cannot be attributed to the presence of kaolinite. These data suggest,

[7] Alluvial soils are composed of transported soil material on which little or no profile has developed.

[8] Zonal soils have well-developed profiles that reflect the influence of the active factors of soil genesis.

instead, that there is uncombined alumina in the eastern colloids or that weathering processes in the more humid east may have removed some silica from or introduced alumina into the illite present throughout the profile. Moreover, in the east the A horizon illite apparently is more degraded with respect to K_2O than the illite in the lower part of the profile, for the eastern zonal soils have a consistently lower K_2O content in

TABLE 1a

Average Compositions

	Molecular SiO_2/Al_2O_3 ratio	per cent K_2O	Clay Minerals Present
A. Alluvial Soils			
Eastern tributaries	2.86	3.05	70% Illite, 10-15% Kaolinite
Western tributaries	3.87	2.58	50-60% Illite, 10-15% Kaolinite
B. Zonal Soils			
Eastern tributaries	A. hor. 3.32	A. hor. 2.08 C. hor. 3.78	65-75% Illite, 10% Kaolinite in B. hor.
Western tributaries	A. hor. 4.14	A. hor. 2.28 C. hor. 2.55	Abundant Illite in B. hor.

their A horizons, whereas in western soils there commonly is no appreciable difference in K_2O content throughout the profiles. If these samples of the zonal soils are representative, it is not clear why eastern alluvial soils have a higher K_2O content than the western ones, inasmuch as alluvial soils are presumably composed largely of little-altered mineral eroded from the higher horizons of zonal soil profiles. The evidence implies, instead, that the C horizon must have contributed much material to the eastern alluvial soil or that there is no direct correlation between the composition of zonal and alluvial soils of the same region.

B

In order to provide more extensive information about the relationship of clay minerals in soils and their parent sedimentary rocks, samples of sedimentary rocks and the A horizon of derived soils from many soil areas (table 2) have been analyzed for the predominant clay mineral group present. The samples were collected south of the southern limit of the glacial

drift sheets, along a route from Wyoming to Oklahoma and Arkansas to New Jersey (fig. 1).

The colloidal fractions of the pairs of samples were treated with H_2O_2 and HCl, and the more abundant clay minerals present were identified by differential thermal and x-ray analysis. In many of the samples the subordinate clay constituents have not been determined, hence these specimens may contain some clay minerals not reported in table 2. Where the presence of montmorillonite was suggested by the differential thermal curves or by published analyses of similar soils, those clays were x-rayed both untreated and after being soaked in glycol. In the clay fractions identified here as "illite and montmorillonite," evidence of these minerals was found in both differential thermal and x-ray curves. Clay fractions recorded as "K-bentonite type" yield a differential thermal curve like that of mixed illite and montmorillonite but an x-ray curve of illite. Some authors consider that K-bentonite is a type of illite, others believe it is a mixed layer mineral or aggregate composed of illite and montmorillonite. The chemical analyses recorded in table 3 (a, b, c) were made by the Rock Analysis Laboratory, Department of Geology, University of Minnesota.

In 35 of the 43 pairs of samples with sedimentary bedrock the predominant clay mineral groups in the soil are the same as those in the parent rock member (table 2). Nevertheless, more detailed analysis undoubtedly would show differences in the proportions of the clay minerals present. It is to be expected that inherited clay minerals characterize the immature lithosols of the Appalachian Mountains (table 2; 32, 33, 40, 41, 42; fig. 2; 33, 42) and the shallow Sierozem (table 2; 1, 2; fig. 2; 1) and Brown (table 2; 3, 6) soils of arid regions. The significant fact revealed by these analyses is the similarity of the predominant clay minerals in most of the samples of zonal soils and their parent rocks from humid regions. Even in southern United States where intense weathering conditions commonly produce primary clay minerals in the soils, many of the kaolinite-rich Red and Yellow Podzolic soils (table 2; 18, 19, 21-27; fig. 2; 25, 27) apparently have inherited their clay from kaolinite-rich parent material, as did the Norfolk soils (table 1; 27).

Of the eight soils whose clay mineral content differs markedly from that of the parent material, one is a kaolinite-rich soil developed on the Boone chert (table 2; 20). The other seven

soils also contain abundant kaolinite, but they have been formed on limestone, dolomite, and calcareous shale rich in illite or a K-bentonite type of clay mineral (table 2; 28, 29, 30, 31, 35, 36, 43). Numerous published analyses show that Paleozoic limestone and dolomite, with a few kaolinite-rich exceptions, contain abundant illite (Grim, Lamar, and Bradley, 1937; Grim, 1951, p. 227), and that soils developed on the Paleozoic calcareous rocks of the Appalachian region (table 1; 7, 10, 11, 14, 15, 23) are consistently kaolinite-rich with some illite (Alexander, Byers, and Edgington, 1939). Apparently the paucity of clay in the parent rock and the acid environment of Red and Yellow Podzolic soils favor the development of abundant primary kaolinite. Nevertheless, some of the predominant illite of the parent rock does persist as inherited illite in the derived soils.

Montmorillonite is an important constituent in many of the analyzed soils and rocks. No attempt has been made to estimate the relative amounts of illite and montmorillonite in most samples rich in these minerals, although the differential thermal curves do suggest that illite is consistently abundant. Significantly, most of the soils rich in montmorillonite (table 2; 1-16) are developed on montmorillonite-rich parent rock. In fact, some of these parent rocks contain relatively more montmorillonite than their derived soils (table 2; 1, 2, 3, 7). This association reveals that at least part of the montmorillonite so prevalent in soils of the western plains has been inherited from montmorillonite-bearing sediments. Nevertheless, montmorillonite in some of the analyzed soils (table 2; 9, 11) is clearly primary, for here it is relatively more abundant than in the parent rocks.

The results of these analyses also reinforce the conclusion that illite is a very common clay mineral group in sedimentary rocks and that it is a "relic" mineral in many soils. The significant resemblance of the differential thermal curves of illite-bearing zonal soils and parent materials (fig. 2; 13, 14, 16) is emphasized by comparison with curves of kaolinite-rich Gray-Brown Podzolic soils developed on mica schist (fig. 2; 37, 44). The presence of illite in these samples does not mean, however, that the colloid contains a clay mineral with as high a K_2O content and molecular SiO_2/Al_2O_3 ratio as Fithian illite. Chemical analyses of the colloidal fraction of three pairs of illite-bearing samples (table 2; 13, 14, 17; table 3; a, b, c) show that their K_2O content and SiO_2/Al_2O_3 ratios are within the range of

composition of the illite-bearing soils listed in table 1. The MgO content of no. 13 and 14 soil and "red bed" parent rock is unusually high, however. The Spearfish soil (table 1; 38) with 10.34 per cent MgO in the C horizon parent material (Spearfish "red bed" formation) is the only one listed with a colloidal fraction MgO content exceeding 4 per cent. The fact that each of these colloids has a low CO_2 content suggests that much of the magnesium is associated with a colloidal silicate mineral. The presence of a magnesium-rich colloid in the Per-

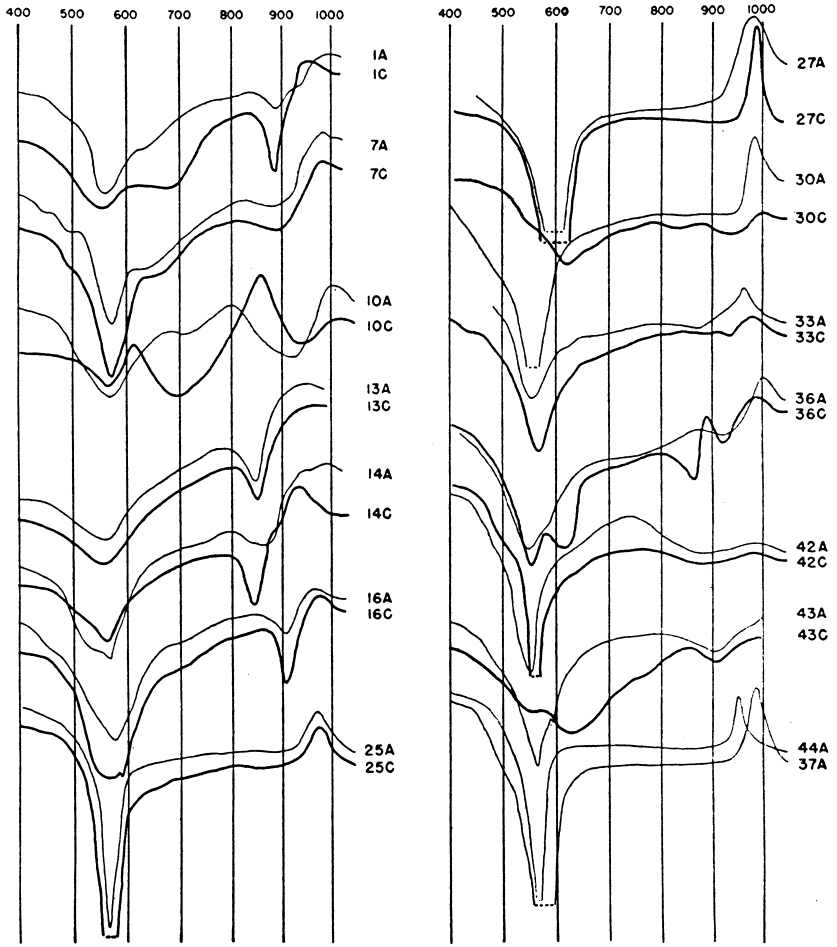

Fig. 2. Differential thermal curves of clay fraction of some rocks and soils listed in table 2.

mian and Triassic "red beds" may possibly be related to the environmental condition under which they formed. If so, it is perhaps significant that the magnesium-rich clay minerals such as attapulgite and sepiolite are abundant in highly alkaline sediments deposited in dry desert basins (Grim, 1951, pp. 228-229).

DISCUSSION OF SOME SOILS AND PARENT ROCKS LISTED IN TABLE 2:

1. The White River formation in this area contains both volcanic ash and sticky "bentonitic" clay. X-ray and differential thermal curves indicate that montmorillonite is more abundant in the parent rock than it is in the derived soil.

2 and 3. Both x-ray and differential thermal curves indicate that montmorillonite is relatively more abundant in the rocks than it is in the soils.

5. The White River formation in Colorado contains volcanic ash as well as some montmorillonite, but apparently not as much of this type of clay as is present in rock sample no. 1. The chemical composition of the rock probably is very similar to that of the Badland lithosol from western South Dakota (table 1; 1) which is developed on the White River formation. The presence of 2.61-2.75 per cent K_2O in the published profile is undoubtedly due to the presence of considerable illite.

3, 4, 6, 7, and 8. The Ogallala formation contains volcanic ash and montmorillonite clay which, according to x-ray analyses, is most abundant in rock sample no. 7. But no great abundance of montmorillonite is indicated by the differential thermal curve (fig. 2).

9 and 11. The similarity of clay content of soil and parent rock accords with the uniform chemical composition of the Hays profile in table 1 (16) which is also developed on Carlisle calcareous shale. The fact that illite appears to be the more abundant clay mineral present agrees with the reported abundance of K-bentonite type mineral in Hays soil (Middleton, Slater, and Byers, 1932).

10 and 12. The analyses of the parent material agree with published reports that loess contains illite and montmorillonite.

13. The Vernon soil colloid in table 1 (40) has a similar K_2O content and is similarly rich in illite for it has been reported to be composed of a K-bentonite type. The higher K_2O content of the parent rock of sample no. 13 suggests that there may

TABLE 2

Soils and Parent Sedimentary Rocks from Numbered Localities on Figure 1.

A. Soil, A horizon
C. Parent rock

I — Illite group
M — Montmorillonite group
K — Kaolinite group

	Soil	Predominant clay mineral group
1.	A. Navajo-Chipeta soils, Sierozem soil group (fig. 2; see table 1;1)	Illite, some Montmorillonite
	25 miles southeast of Riverton, Fremont Co., Wyo.	
	C. Oligocene White River tuffaceous sandstone (non-marine)	Illite and Montmorillonite
2.	A. Navajo-Chipeta soils, Sierozem soil group	Illite and Montmorillonite
	Route 30, 2 miles east of Rock River, Albany Co., Wyo.	
	C. Upper Cretaceous Steele shale and sandstone (marine)	Montmorillonite and Illite
3.	A. Joplin soil, Brown soil group	Illite, some Montmorillonite
	Route 30, 11 miles west of Cheyenne, Laramie Co., Wyo.	
	C. Pliocene Ogallala arkose (non-marine)	Illite and Montmorillonite
4.	A. Rosebud-Bridgeport soils, Chestnut soil group	Illite and Montmorillonite
	Route 30, 20 miles east of Cheyenne, Laramie Co., Wyo.	
	C. Pliocene Ogallala arkosic conglomerate (non-marine)	Illite and Montmorillonite
5.	A. Rosebud-Bridgeport soils, Chestnut soil group (see table 1;1)	Illite and Montmorillonite
	Route 155, 2 miles south of Hereford, Weld Co., Colo.	
	C. Oligocene White River tuffaceous siltstone (non-marine)	Illite and Montmorillonite
6.	A. Fort Collins soils, Brown soil group	Illite and Montmorillonite
	Route 34, 2 miles west of Akron, Washington Co., Colo.	
	C. Pliocene Ogallala arkose (non-marine)	Illite and Montmorillonite
7.	A. Keith soil, Chestnut soil group (fig. 2; see table 1; 20)	Illite and Montmorillonite, little K
	Route 24, 16 miles west of Colby, Thomas Co., Kan.	
	C. Pliocene Ogallala arkosic sandstone (non-marine)	Illite and Montmorillonite, little K
8.	A. Holdrege-Hall soils, Chernozem soil group	Illite and Montmorillonite
	Route 24, 1.5 miles west of Hoxie, Sheridan Co., Kan.	
	C. Pliocene Ogallala arkosic sandstone (non-marine)	Illite and Montmorillonite
9.	A. Hays soil, Chernozem soil group (see table 1;16)	Illite and Montmorillonite
	Route 283, 1 mile south of Smoky Hill River, Trego Co., Kan.	
	C. Upper Cretaceous Niobrara chalk (marine)	Illite, little Montmorillonite
10.	A. Holdrege-Hall soils, Chernozem soil group (fig. 2)	Illite and Montmorillonite
	Route 283, 1 mile north of Jetmore, Hodgeman Co., Kan.	
	C. Pleistocene loess (non-marine)	Illite and Montmorillonite
11.	A. Hays soil, Chernozem soil group (see table 1;16)	Illite and Montmorillonite
	Route 50, 5 miles west of Jetmore, Hodgeman Co., Kan.	
	C. Upper Cretaceous Carlisle calcareous shale (marine)	Illite, some Montmorillonite
12.	A. Holdrege-Hall soils, Chernozem soil group	Illite and Montmorillonite
	14 miles west of Ford, Ford Co., Kan.	
	C. Pleistocene loess (non-marine)	Illite and Montmorillonite
13.	A. Miles-Vernon soils, Reddish Chestnut soil group (fig. 2; table 3,a; see table 1;40)	Illite and Montmorillonite
	Route 160, 15 miles west of Medicine Lodge, Barber Co., Kan.	
	C. Permian Cimarron red siltstone	Illite and Montmorillonite
14.	A. Zaneis-Renfrow soils, Reddish Prairie soil group (fig. 2; table 3,b)	Illite, some Montmorillonite
	Route 160, 7 miles east of Attica, Harper Co., Kan.	
	C. Permian Cimarron red siltstone	Illite, some Montmorillonite
15.	A. Zaneis-Renfrow soils, Reddish Prairie soil group	Illite, some Montmorillonite
	Route 160, 17 miles west of Wellington, Summer Co., Kan.	
	C. Permian Cimarron sandstone	Illite, some Montmorillonite
16.	A. Summit-Bates soils, Prairie soil group (fig. 2)	Illite, some Montmorillonite
	Route 160, 4 miles east of Winfield, Cowley Co., Kan.	
	C. Permian Big Blue calcareous shale (marine)	Illite, some Montmorillonite
17.	A. Florence-Newtonia soils, Prairie soil group (see table 3;c)	Illite and Kaolinite
	Route 166, 1 mile east of Cedarvale, Chautauqua Co., Kan.	
	C. Pennsylvanian Wabaunsee sandstone (cyclothem)	Illite and Kaolinite
18.	A. Parsons and associated soils, Planosol group	Kaolinite and Illite
	Route 60, 6 miles east of Nowata, Nowata Co., Okla.	
	C. Pennsylvanian Coffeyville micaceous siltstone	Kaolinite, some M. and Illite
19.	A. Parsons and associated soils, Planosol group	Kaolinite, some Illite
	Route 67, 17 miles north of Pryor, Craig Co., Okla.	
	C. Pennsylvanian Cherokee sandstone (cyclothem)	Kaolinite, some Illite and M.
20.	A. Baxter-Lebanon soils, Red and Yellow Podzolic soil group (see table 1;21)	Kaolinite
	Route 33, 4 miles west of Kansas, Delaware Co., Okla.	
	C. Mississippian Boone chert and cherty limestone (marine)	Chert
21.	A. Hanceville-Conway soils, Red and Yellow Podzolic soil group	Kaolinite, some Illite
	Route 71, 28 miles south of Fayetteville, in Crawford Co., Ark.	
	C. Pennsylvanian Atoka gray shale	Kaolinite, some Illite
22.	A. Hanceville-Conway soils, Red and Yellow Podzolic soil group	Kaolinite, some Illite
	Route 64, 9 miles west of Ozark, Franklin Co., Ark.	
	C. Pennsylvanian shale	Kaolinite, some Illite and M.
23.	A. Hanceville-Conway soils, Red and Yellow Podzolic soil group	Kaolinite and Illite
	Route 64, 7 miles east of Clarksville, Johnson Co., Ark.	
	C. Pennsylvanian McAlester shale	Kaolinite, little Illite

TABLE 2 (*Cont.*)

Soils and Parent Sedimentary Rocks from Numbered Localities on Figure 1.

A. Soil, A horizon
C. Parent rock

I — Illite group
M — Montmorillonite group
K — Kaolinite group

	Soil	Predominant clay mineral group
24.	A. Norfolk-Ruston soils, Red and Yellow Podzolic soil group (See table 1;27)	Kaolinite
	Route 270, 1 mile west of Sheridan, Grant Co., Ark.	
	C. Eocene Claiborne sandy clay (lagoonal)	Kaolinite
25.	A. Caddo-Beauregard soils, Red and Yellow Podzolic soil group (fig. 2)	Kaolinite
	Route 167, 19 miles north of Sheridan, Grant Co., Ark.	
	C. Eocene Claiborne sandstone (lagoonal)	Kaolinite
26.	A. Memphis-Grenada soils, Red and Yellow Podzolic soil group	Kaolinite
	Route 79, 6 miles east of Stanton, Haywood Co., Tenn.	
	C. Eocene Grenada sandy clay (Wilcox group) (lagoonal)	Kaolinite
27.	A. Memphis-Grenada soils, Red and Yellow Podzolic soil group (fig. 2)	Kaolinite, some Illite
	Route 70, 4 miles northeast of Jackson, Madison Co., Tenn.	
	C. Eocene Wilcox sandy clay (lagoonal)	Kaolinite
28.	A. Dickson-Baxter soils, Red and Yellow Podzolic soil group	Kaolinite and Illite
	Route 70, 1 mile east of Camden, Benton Co., Tenn.	
	C. Devonian calcareous shale and limestone (marine)	K-bentonite type, a little Kaolinite
29.	A. Dickson-Baxter soils, Red and Yellow Podzolic soil group	Kaolinite, some Illite
	Route 70, 2 miles east of Dickson, Dickson Co., Tenn.	
	C. Mississippian limestone (marine)	Illite and Montmorillonite, little K.
30.	A. Maury soil, Red and Yellow Podzolic soil group, (fig. 2; see table 1; 23)	Kaolinite
	Route 70N, 8 miles east of Lebanon, Wilson Co., Tenn.	
	C. Ordovician phosphatic limestone (marine)	Illite
31.	A. Maury soil, Red and Yellow Podzolic soil group (see table 1, 23)	Illite and Kaolinite
	Route 70N, 9 miles east of Carthage, Smith Co., Tenn.	
	C. Ordovician phosphatic limestone and shale (marine)	Illite
32.	A. Hartsells-Muskingum soils, Lithosol group (Red and Yellow Podzolic soil group)	Kaolinite and Illite
	Route 70N, 3 miles west of Monterey, Putnam Co., Tenn.	
	C. Mississippian sandstone and shale	Kaolinite, some Illite
33.	A. Hartsells-Muskingum soils, Lithosol group (Red and Yellow Podzolic soil group)	Illite and Kaolinite
	Route 70, 3 miles east of Ozone, Cumberland Co., Tenn.	
	C. Pennsylvanian Lee sandstone and shale (delta, non-marine?)	Illite and Kaolinite
34.	A. Decatur-Dewey-Clarksville soils, Red and Yellow Podzolic soil group	Illite, some Kaolinite
	Route 25E, 9 miles west of Mooresburg, Grainger Co., Tenn.	
	C. Mississippian carbonaceous shale (non-marine)	Illite
35.	A. Hagerstown-Frederick soils, Gray-Brown Podzolic soil group (see table 1;10,14,15)	Kaolinite and Illite
	Route 11W, 3 miles northeast of Mooresburg, in Hawkins Co., Tenn.	
	C. Ordovician Calcareous reddish brown shale (marine)	Illite (K-bentonite type?)
36.	A. Hagerstown-Frederick soils, Gray-Brown Podzolic soil group (fig. 2; see table 1;10,14,15)	Kaolinite and Illite
	Route 19, 1 mile west of Abingdon, Washington Co., Va.	
	C. Ordovician Knox dolomite (marine)	K-bentonite type
37.	A. Porters-Ashe soils, Gray-Brown Podzolic soil group (fig. 2)	Kaolinite
	2 miles east of Lynchburg, Campbell Co., Va.	
	C. Precambrian mica schist	Micaceous material
38.	A. Dekalb-Leetonia soils, Podzol soil group	Illite, some Kaolinite
	Route 250, 15 miles south of Elkins, Randolph Co., W. Va.	
	C. Upper Devonian shale (marine)	Illite, M., some Kaolinite
39.	A. Muskingum-Wellston-Zanesville soils, Gray-Brown Podzolic soil group	Kaolinite and Illite
	Route 250, 3 miles northwest of Phillipi, Barbour Co., W. Va.	
	C. Pennsylvanian Conemaugh sandstone and shale (non-marine)	Kaolinite and Illite
40.	A. Muskingum soil, Lithosol group (Podzol soil group)	Illite
	Route 50, 4 miles east of Aurora, Preston Co., W. Va.	
	C. Mississippian Pocono gray sandstone and shale (non-marine)	Illite
41.	A. Muskingum soil, Lithosol group (Gray-Brown Podzolic soil group)	Illite
	Penn. Turnpike, Clear Ridge Cut, Bedford Co., Penn.	
	C. Upper Devonian Marcellus shale (marine)	Illite
42.	A. Muskingum soil, Lithosol group (Gray-Brown Podzolic soil group) (fig. 2)	Illite and Kaolinite
	Penn. Turnpike, Tuscarora Tunnel, Huntingdon Co., Penn.	
	C. Upper Devonian Portage shale (marine)	Illite and Kaolinite
43.	A. Hagerstown soil, Gray-Brown Podzolic soil group (fig. 2; see table 1;14,15)	Illite and Kaolinite
	Route 11, 8 miles south of Chambersburg, Franklin Co., Penn.	
	C. Lower Ordovician limestone (marine)	K-bentonite type
44.	A. Manor soil, Gray-Brown Podzolic soil group (fig. 2)	Kaolinite
	Safe Harbor, Lancaster Co., Penn.	
	C. Precambrian? Wissahickon schist	Micaceous material
45.	A. Penn soil, Gray-Brown Podzolic soil group	Illite
	5 miles north of Princeton, Mercer Co., New Jersey	
	C. Triassic Brunswick red-brown shale (non-marine)	Illite

TABLE 3
Chemical Analysis

	a		b		c		d	e	f	g	h	i	j	k
	C	A	C	A	C	A								
SiO_2	50.66	39.59	47.49	50.80	52.04	50.79	56.91	57.41	50.95	57.49	44.39	67.51	53.43	49.50
Al_2O_3	16.29	15.46	18.17	17.84	24.73	18.61	18.50	17.96	16.54	20.27	18.11	15.09	21.59	21.75
Fe_2O_3	6.30	5.49	8.82	7.36	4.04	6.45	4.99	4.99	1.36	2.92	1.60	4.29	1.04	8.81
FeO	0.89	0.61	0.84	0.73	1.18	0.81?	0.26	0.26	0.26	0.19	0.50	1.26	tr	0.42
MgO	7.47	8.73	6.92	4.12	1.59	1.55	2.07	2.25	4.65	3.18	2.24	1.55	4.17	1.99
CaO	1.36	6.91	1.26	2.00	0.70	3.00	1.59	0.64	2.26	0.23	11.35	0.11	0.53	0.28
Na_2O	0.52	0.24	0.60	0.64	0.58	0.29	0.43	0.15	0.17	1.32	0.64	0.40	0.11	0.44
K_2O	3.17	2.32	4.37	4.09	4.34	2.87	5.10	5.75	0.47	0.28	4.40	2.77	7.00	0.94
H_2O+	6.37	7.51	6.23	6.26	6.65	7.06	5.98	6.70	8.28	6.85	4.34	4.43	6.67	13.05
H_2O-	5.94	7.76	4.21	4.20	2.76	4.90	2.86	2.97	15.01	7.63	3.28	1.36	5.70	
CO_2	0.04	3.84	0.41	0.24	0.00	0.15	....	....	....	....	8.43	0.97	0.28	....
TiO_2	0.74	0.64	0.80	0.86	1.25	0.85	0.81	0.82	0.32	0.12	0.36	0.09	....	0.70
P_2O_5	0.04	0.26	0.08	0.23	0.18	0.33	....	....	....	....	0.11	....	....	2.16
MnO	0.05	0.05	0.05	0.08	0.02	0.06	....	....	.01	....	0.02	0.04	....	0.02
ign. loss	0.21	0.83	0.00	0.50	0.00	2.25	....	....	....	....	....	....	....	....
mol. SiO_2/Al_2O_3	5.30	4.35	4.44	4.82	3.59	4.62	5.23	5.42	5.18	4.39	4.15	7.56	4.45	3.86

a. see table 2; 13.
   A — soil, A horizon, colloidal fraction
   C — parent rock, colloidal fraction

b. see table 2; 14.
   A — soil, A horizon, colloidal fraction
   C — parent rock, colloidal fraction

c. see table 2; 17.
   A — soil, A horizon, colloidal fraction
   C — parent rock, colloidal fraction

d. Illite; Fithian, Ill., Kerr, *et al.*, 1950*b*.

e. Illite; Morris, Ill., Kerr, *et al.*, 1950*b*

f. Montmorillonite; Polkville, Miss., Kerr, *et al.*, 1950*b*

g. Montmorillonite; Upton, Wyo., Kerr, *et al.*, 1950*b*

h. Mixed layer aggregate (K-bentonite); Tazewell, Va., Kerr, *et al.*, 1950*b*

i. Mixed layer aggregate (K-bentonite); Catawba, Va., Kerr, *et al.*, 1950*b*

j. Mixed layer aggregate (K-bentonite); High Bridge, Ky., Kerr, *et al.*, 1950*b*

k. Putnam soil, Mixed layer aggregate or beidellite; Ross and Hendricks, 1945.

be more illite in the rock than in the derived soil. Although x-ray curves clearly indicate the presence of some montmorillonite in both soil and parent material, illite probably is the predominant clay mineral present as suggested by the differential thermal curves (fig. 2).

14 and 15. Differential thermal curves and the high K_2O content of sample no. 14 indicate an abundance of illite in both soil and rock. X-ray curves show that there is relatively less montmorillonite than in rock and soil no. 13.

18 and 19. The presence of some montmorillonite in the rocks and its absence in the derived soils strongly suggests that this clay mineral is actually destroyed by soil-forming processes here as in soils nos. 1, 2 and 3.

22 and 23. Both soils and parent rocks contain kaolinite and illite, but the soil of sample no. 23 contains relatively more illite and less kaolinite than its parent rock or than the same kind of soil of sample no. 22.

24. Clay mineral content is like that of the Norfolk soil and parent material in table 1 (27) and presumably the chemical compositions are similar.

27. The presence of some illite in the soil of a kaolinite-rich sample suggests that the illite may be primary, but this seems anomalous in a warm, humid climate where intense weathering readily produces kaolinite. A similar relative increase of illite over kaolinite was noted in sample no. 22.

30 and 31. The chemical composition probably is like that of Maury soil and parent material in table 1 (23). The higher K_2O content and molecular SiO_2/Al_2O_3 ratio in the C horizon correlates with the abundance of illite in the parent rock and its alteration to kaolinite in the soil.

33. The small endothermic deflections of about 630° in the differential thermal curves (fig. 2) of both rock and soil suggest that a K-bentonite type of mineral may be present, inasmuch as there is no shift of the x-ray peaks after glycol treatment.

34. Decatur-Dewey-Clarksville soils normally develop on limestone and dolomite and are kaolinite-rich throughout the profile (table 1; 7). The abundant illite in the soil in this sample undoubtedly has been derived from the illite in the parent shale.

35, 36, and 43. As in these soils developed on limestone and dolomite, published Hagerstown and Frederick profiles (table 1; 10, 14, 15) contain kaolinite and illite, but no montmorillonite—

a composition that is reflected in their low K_2O content and molecular SiO_2/Al_2O_3 ratios.

42. The matching differential thermal curves of this pair of samples (fig. 2) are unusual in that x-ray curves indicate the presence of kaolinite yet there is no sharp exothermic peak of kaolinite at 980° on the differential thermal curves.

45. Abundant illite in the non-marine Brunswick shale (Triassic) and in the fine-grained facies of the Stockton sandstone (Triassic) of New Jersey contradicts the generalization of some authors that kaolinite is the predominant clay mineral in non-marine sedimentary rocks.

CONCLUSION

The data assembled and discussed in this study support the conclusion that the clay mineral complex in soils developed on sedimentary rocks is commonly inherited from the parent material. Because illite is a very common constituent in the widespread mantle of sedimentary rocks, many of its derived soils contain an abundance of "relic" illite. In view of this relationship statements concerning the kind of climate favoring the formation of illite in soils must be based on examples containing authigenic illite, for inherited illite is present in soils in a wide variety of environmental conditions. The evidence adduced here also indicates that derived kaolinite is abundant in many of the soils developed on the Coastal Plain deposits of the southern regions. Montmorillonite is not commonly the predominant mineral in the clay fraction of soils, although it is associated with illite in both soils and sedimentary rocks.

A significant implication of these conclusions is that the alluvium eroded from widespread illite-bearing soils should contain considerable quantities of that clay mineral. Grim, Dietz, and Bradley (1949) have shown that illite is as abundant as kaolinite and montmorillonite in the clay fraction of the Little Colorado alluvium (table 1; 42) and in the clay fraction of near-shore deposits along the Pacific Coast (table 1; 43). In the sediments of the Gulf of California and in the deeper Pacific Ocean (table 1; 44, 45, 46), on the other hand, illite is most abundant and kaolinite least abundant. The authors believe that "the clay debris carried to the sea in many areas undoubtedly contains much degraded illite" (p. 1806) and have interpreted the increase in proportion of illite in off-shore marine sediments

as resulting from the slow loss of some of the kaolinite during diagenesis under marine conditions. The difference between the K_2O content of the Little Colorado alluvium and that of Gulf of California sediments (fig. 3; F, H) was thought to indicate that the degraded illite carried to the sea "would rapidly pick up potassium . . . because of its great avidity" for K_2O (p. 1806).

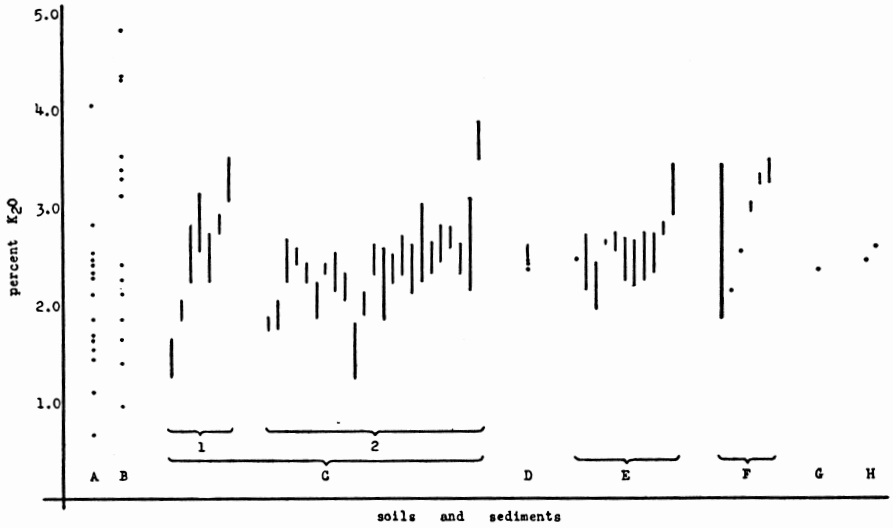

Fig. 3. K_2O Content of soils and sediments.
Dot—content of single analyzed sample.
Line—range of content in profiles with several analyzed samples.
A. A horizons of illite-bearing soils (tables 1 and 2).
B. Parent material or C horizons of illite-bearing soils (tables 1 and 2).
C. Alluvial soils of Mississippi drainage basin (Tech. Bull. 883).
1. Samples analyzed for clay mineral content (table 1; 47-53).
2. Other samples.
D. Gulf of Mexico sediments (Tech. Bull. 883).
E. Sediments of Pacific Ocean (Grim, *et al.*, 1949).
F. Sediments of Gulf of California (Grim, *et al.*, 1949).
G. Sediment of Mission Bay, California (Grim, *et al.*, 1949).
H. Little Colorado River alluvium, Arizona (Grim, *et al.*, 1949).

But comparison of their data with the K_2O content of soils, alluvium, and other marine deposits (fig. 3) does not suggest this conclusion. The amount of K_2O in the soils and alluvium of the Mississippi drainage basin, for example, shows no consistent variation with respect to that in the Gulf of Mexico deposits.

A detailed study of alluvial soils of the Mississippi River and its eastern and western tributaries (Holmes and Hearn, 1942) demonstrates conclusively that illite is the dominant clay mineral in the alluvium of this great drainage basin (table 1; 47-54). The analyses also reveal that the colloidal fractions of samples of sediments from the Gulf of Mexico (table 1; 55, 56) have essentially the same composition as the colloidal fractions of Mississippi delta alluvium, thus indicating that the composition of the alluvium contributed by the drainage system apparently is altered but little by the marine environment of the Gulf of Mexico.

From the source areas to depositional basins illite commonly is an abundant clay mineral. In many parts of the United States it is inherited in the soil from ancient sedimentary rocks, it is preserved in transportation and incorporated in modern sediments. But the inherited illite generally has been altered somewhat by weathering processes in the source area and as a result it has a variable K_2O content and molecular SiO_2/Al_2O_3 ratio. This alteration of illite should provide significant information about the effects of soil-forming processes, and it is obscured when illite minerals of differing composition are all identified as "illite" without more specific identification.

Throughout this discussion the similarity of the clay minerals in soil and parent sedimentary rock has been stressed. This emphasis is not intended to suggest that differences in composition between parent rock and derived soil or between different soils are not important or that authigenic clay minerals in soils are insignificant. Chemical analyses of profiles of Podzol soils, for example, show clearly that extensive fractionation of colloidal substances takes place in many soils developed on sedimentary materials. Similarly, the molecular SiO_2/Al_2O_3 ratios of the colloidal fractions of the Norfolk soils which contain inherited kaolinite range from 1.46 to 2.61. Inasmuch as this variation is clearly the result of different soil-forming conditions, it is important to an understanding of soil genesis. It should also be recalled that even though a soil contains some inherited illite, it may contain primary clay minerals produced by weathering of detrital minerals of the parent rock.

The kinds of materials and the relationship of the processes discussed here may result from environmental conditions peculiar to the present time, and may therefore be of limited use in

paleogeographic interpretations. Much of the soil that supplies the illite-rich alluvium of the Mississippi drainage basin is formed on widespread, illite-rich glacial drift and loess. Such glacial deposits were not common parent material during geologic history. In ancient times of more extensive seas, igneous and metamorphic rocks presumably were a greater proportion of the upland source areas than they are today, and on these crystalline rocks authigenic clay minerals developed in the soil.

References

Alexander, L. T., Byers, H. G., and Edgington, G., 1939. A chemical study of some soils derived from limestone: U. S. Dept. Agr. Tech. Bull. 678.

———, Hendricks, S. B., and Nelson, R. A., 1939. Minerals present in soil colloids: II. Estimation in some representative soils: Soil Science, vol. 48, pp. 273-279.

Barshad, Isaac, 1946. A pedologic study of California Prairie soils: Soil Science, vol. 61, pp. 423-442.

Bidwell, O. W., and Page, J. B., 1951. The effects of weathering on the clay mineral composition of soils in the Miami catena: Soil Science Soc. America Proc., vol. 15, pp. 314-318.

Bray, R. H., 1934. A chemical study of soil development in the Peorian loess region of Illinois: Am. Soil Survey Assoc., 14th Ann. Rept., Bull. 15, pp. 58-65.

Brown, I. C., and Byers, H. G., 1937. The chemical and physical properties of dry-land soils and their colloids: U. S. Dept. Agr. Tech. Bull. 502.

———, and Thorpe, J., 1942. Morphology and composition of some soils of the Miami family and the Miami catena: U. S. Dept. Agr. Tech. Bull. 834.

Byers, H. G., Alexander, L. T., and Holmes, R. S., 1935. The composition and constitution of certain of the great groups of soils: U. S. Dept. Agr. Tech. Bull. 484.

Caldwell, A. C., and Rost, C. O., 1942. Chemical composition of the clay fraction of the Black Prairie soils of Minnesota: Soil Science, vol. 53, pp. 249-263.

Grim, R. E., 1941. The clay minerals in soils and their significance: Illinois Geol. Survey Circ. 65, pp. 9-14.

———, 1947. Differential thermal curves of prepared mixtures of clay minerals: Am. Mineralogist, vol. 32, pp. 493-501.

———, 1951. The depositional environment of red and green shales: Jour. Sedimentary Petrology, vol. 21, pp. 226-232.

———, Bray, R. H., and Bradley, W. F., 1937. The mica in argillaceous sediments: Am. Mineralogist, vol. 22, pp. 813-829.

———, Dietz, R. S., and Bradley, W. F., 1949. Clay mineral composition of some sediments from the Pacific Ocean off the California coast and the Gulf of California: Geol. Soc. America Bull., vol. 60, pp. 1785-1808.

———, Lamar, J. E., and Bradley, W. F., 1937. The clay minerals in Illinois limestones and dolomites: Jour. Geology, vol. 45, pp. 829-843.

———, and Rowland, R. A., 1942. Differential thermal analysis of clay minerals and other hydrous materials: Am. Mineralogist, vol. 27, pp. 746-761, 801-818.

Hendricks, S. B., and Alexander, L. T., 1939. Minerals present in soil colloids: I. Description and methods for identification: Soil Science, vol. 48, pp. 257-271.

———, and Fry, W. H., 1930. The results of x-ray and microscopical examinations of soil colloids: Soil Science, vol. 29, pp. 457-476.

Holmes, R. S., and Hearn, W. E., 1942. Chemical and physical properties of some important alluvial soils of the Mississippi drainage basin: U. S. Dept. Agr. Tech. Bull. 833.

———, ———, and Byers, H. G., 1938. The chemical composition of soils and colloids of the Norfolk and related soil series: U. S. Dept. Agr. Tech. Bull. 594.

Hunt, C. B., and Sokoloff, V. P., 1950. Pre-Wisconsin soil in the Rocky Mountain region: U. S. Geol. Survey Prof. Paper 221-G, pp. 109-123.

Hursh, R. K., Lamar, J. E., and Grim, R. E., 1944. Illinois clays and shales as mortar mix: Illinois State Geol. Survey, Rept. Inv. 100.

Jackson, M. L., Tyler, S. A., Willis, A. L., Bourbeau, G. A., and Pennington, R. P., 1948. Weathering sequence of clay-size minerals in soils and sediments, part I: Jour. Phys. and Coll. Chem., vol. 52, pp. 1237-1260.

Jeffries, C. D. and Yearick, L. G., 1949. The essential mineral content of the principle soil series of Union County, Pennsylvania: Soil Science Soc. Amer. Proc., vol. 13, pp. 146-152.

Keller, W. D., and Ting, C. P., 1950. The petrology of a specimen of the Perry Farm shale: Jour. Sedimentary Petrology, vol. 20, pp. 123-132.

Kelley, W. P., Dore, W. H., Woodford, A. O., and Brown, S. M., 1939. The colloidal constituents of California soils: Soil Science, vol. 48, pp. 201-255.

———, ———, and Page, J. B., 1941. The colloidal constituents of American alkali soils: Soil Science, vol. 51, pp. 101-124.

———, Woodford, A. O., Dore, W. H., and Brown, S. M., 1939. Comparative study of the colloid of a Cecil and a Susquehanna soil profile: Soil. Science, vol. 47, pp. 175-193.

Kerr, P. F., *et al.,* 1950*a*. Occurrence and microscopic examination of reference clay mineral specimens: Am. Petroleum Inst., Project 49, Prelim. Rept. 5.

———, 1950*b*. Analytical data on reference clay minerals: Am. Petroleum Inst., Project 49, Prelim. Rept. 7.

Kurtz, T., DeTurk, E. E., and Bray, R. H., 1946. Phosphate adsorption by Illinois soils: Soil Science, vol. 61, pp. 111-124.

Larson, W. E., Allaway, W. H., and Rhoades, N. F., 1947. Characteristics of the clay fraction of various horizons of Scott silt loam and Pawnee silt loam: Soil Science Soc. America Proc., vol. 11, pp. 443-447.

Middleton, H. E., Slater, C. S., and Byers, H. G., 1932. Physical and chemical characteristics of the soils from the erosion experiment stations: U. S. Dept. Agr. Tech. Bull. 316.

Nelson, R. A., and Hendricks, S. B., 1943. The specific surface of some clay minerals, soils, and soil colloids: Soil Science, vol. 56, pp. 285-296.

Pearson, R. W., and Ensminger, L. E., 1949. Types of clay minerals in Alabama soils: Soil Science Soc. America Proc., vol. 13, pp. 153-156.

Peterson, J. B., 1946. Relation of parent material and environment to the clay minerals in Iowa soils: Soil Science, vol. 61, pp. 465-475.

Ross, C. S., 1945. Minerals and mineral relationships of the clay minerals: Am. Ceramic Soc. Jour., vol. 28, pp. 173-183.

———, and Hendricks, S. B., 1945. Minerals of the montmorillonite group: U. S. Geol. Survey Prof. Paper 206-B, pp. 23-79.

Russell, M. B., and Haddock, J. L., 1941. The identification of the clay minerals in five Iowa soils by the thermal method: Soil Science Soc. America Proc., vol. 5, pp. 90-94.

Swineford, A., and Frye, J. C., 1951. Petrography of the Peoria loess in Kansas: Jour. Geology, vol. 58, pp. 306-322.

Van Houten, F. B., 1948. Origin of red-banded early Cenozoic deposits in Rocky Mountain region: Am. Assoc. Petroleum Geologists Bull., vol. 32, pp. 2083-2126.

Weaver, C. E., and Bates, T. F., 1950. K-bentonite of central Pennsylvania: ONR Project NR081-098, Tech. Rept. 2.

———, ———, 1951. Classification of the 2:1 minerals; ONR Project NR081-098, Tech. Rept. 4.

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