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STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION
DIVISION OF THE
STATE GEOLOGICAL SURVEY
M. M. LEIGHTON, *Chief*

REPORT OF INVESTIGATIONS — NO. 26

PETROGRAPHY OF THE FULLER'S EARTH
DEPOSITS, OLMSTEAD, ILLINOIS
WITH A BRIEF STUDY OF SOME NON-ILLINOIS EARTHS

BY
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STATE GEOLOGICAL SURVEY DIVISION

M. M. LEIGHTON, *Chief*

PETROGRAPHY OF THE FULLER'S EARTH DE-
POSITS, OLMSTEAD, ILLINOIS, WITH A BRIEF
STUDY OF SOME NON-ILLINOIS EARTHS.¹

RALPH E. GRIM.

INTRODUCTION.

THE term "fuller's earth" is herein applied to any clay that has a high capacity for removing color from animal, vegetable, or mineral oils. No particular composition, texture, or genesis is implied by the term, although decolorizing ability may be related to these factors. The name was derived from the original use of earth for removing grease and fat from woolen cloth during the process of fulling.

Much of the fuller's earth in continental Europe is produced by weathering of basic igneous rocks or is a sedimentary product derived from them. As a result the term fuller's earth (*Walkererde*) as used by some workers,² notably the Germans, has had a genetic implication. In England the term has been used also as a formation name. Elsewhere clays of a wider variety are used for bleaching and the term has had no genetic or stratigraphic significance.

Acknowledgments.—Drs. C. S. Ross and P. G. Nutting of the United States Geological Survey, the State Geologists of Florida, Georgia, Arkansas, and Texas, the Standard Oil Company of Indiana, the Sinclair Refining Corporation, and L. A. Salomon and Brother, Importers, supplied the samples of non-Illinois bleaching clays. Various colleagues on the Illinois Geological Survey staff have offered helpful discussion.

OLMSTEAD FULLER'S EARTH.

Occurrence.—At the present time all the fuller's earth produced in Illinois is mined near Olmstead, Pulaski County, in the

¹ Published with the permission of the Chief, Illinois State Geological Survey.

² Dammer, B., and Tietze, O.: *Die Nutzbaren Mineralen*, pp. 419-429, Enke, Stuttgart, 1914.

extreme southern part of the State. The deposits occur in the upper part of the Porters Creek formation of the Midway group of the Eocene system.³ The Porters Creek formation in Illinois is composed of clay deposited in a near-shore marine environment and is fairly uniform lithologically. It occurs in a belt extending across the southern part of Illinois.⁴ In a future paper it is planned to discuss in detail the sedimentation of the Porters Creek clay.

Lithology.—The fuller's earth as exposed in the pits of the Standard Oil Company of Indiana and of the Sinclair Refining Corporation consists of (1) a top, slightly sandy, light gray clay 10 to 20 feet thick; (2) a middle, very sandy gray clay about 10 feet thick; and (3) a bottom, dark gray, very sandy clay which extends below the lowest level of the pits. Only the two upper horizons are used commercially as fuller's earth. The boundaries between the horizons are irregular and gradational. The sandy content varies from about 10 per cent. in the top horizon to as much as 55 per cent. in the basal beds. The sand occurs in small lenticular aggregates scattered through the clay and as individual disseminated grains. The lenticular sandy masses are commonly stained yellow by limonitic material which is believed to have been produced by the alteration of glauconite contained in the clay. Thin beds of yellow limonitic clay are irregularly interstratified with the gray clay.

All the clay is dark brown to dark gray and sticky and slippery when wet. It is tough, breaks with a conchoidal fracture, lacks pronounced bedding, and is difficult to disaggregate in water. It is not fossiliferous except for a few microscopic cellular masses that are probably of organic origin.

Mineral Composition.

The chief constituents in the order of their abundance are montmorillonite, quartz, muscovite, glauconite, and amorphous silica. A few other minerals are extremely rare.

³ Lamar, J. E.: Preliminary Report on the Fuller's Earth Deposits of Pulaski County. Illinois Geol. Survey, Rept. of Inves. 15, p. 10, 1928.

⁴ Lamar, J. E.: *Idem*, p. 31. Lamar, J. E., and Sutton, A. H.: Cretaceous and Tertiary Sediments of Kentucky, Illinois, and Missouri. Bull. Amer. Assoc. Pet. Geol., vol. 14, pp. 845-866, 1930.

Montmorillonite.—The dominant and characteristic mineral is montmorillonite, $(Mg, Ca)O \cdot Al_2O_3 \cdot 5SiO_2 \cdot (5-8)H_2O$,⁵ which was identified by its optical data, chemical analyses, dehydration curves, and X-ray data, which are similar to corresponding data furnished by type montmorillonite (Tables I-IV, Figs. 1 and 2).

TABLE I.
OPTICAL PROPERTIES OF MONTMORILLONITE.

	α	γ	$\gamma - \alpha$	2ν	Optical Character
Olmstead, Illinois:					
Top horizon, Standard pit.	1.500	1.523 ± .003	.023	13° ±	(-)
Middle horizon, Standard pit.	1.499	1.522	.022	small	(-)
Bottom horizon, Standard pit.	1.500	1.523	.022	small	(-)
Top horizon, Sinclair pit.	1.500	1.523	.022	small	(-)
Middle horizon, Sinclair pit.	1.499	1.522	.022	13° ±	(-)
Bottom horizon, Sinclair pit.	1.500	1.523	.022	12° ±	(-)
Other localities: ^a					
Otay, San Diego Co., Calif.	1.492	1.513	.021	16°-24°	(-)
Maricopa, Kern Co., Calif.	1.492	1.515	.023	15°-22°	(-)
Fort Steel, Wyo.	1.484	1.508	.024	13°-24°	(-)
Wisconsin, Tex.	1.493	1.515	.022	7°-19°	(-)
Quilchena, B. C.	1.487	1.514	.027	18° ±	(-)
Rideout, Utah.	1.478	1.500	.022	10°-16°	(-)
Montmorillon, France.	1.503	1.527	.024		(-)
Bainbridge, Ga.	1.512	1.535	.023	17°-25°	(-)

^a Ross, C. S., and Shannon, E. V.: *Op. cit.*, pp. 95-96.

The optical data of the Olmstead clay mineral and of montmorillonite from other localities agree within reasonable limits (Table I). The chemical analyses of the Olmstead clay mineral agree fairly well with the other analyses of montmorillonite (Table II). The variations between the Olmstead clay mineral and the type or theoretical montmorillonite are no greater than the variations between various montmorillonites, nor does the Olmstead mineral vary appreciably in different parts of the deposit. The dehydration curves of the Olmstead clay mineral (Fig. 1) are similar to those published⁶ for clays that will be

⁵ Ross, C. S., and Shannon, E. V.: *The Minerals of Bentonite and Related Clays and their Physical Properties*. Jour. Amer. Cer. Soc., vol. 9, p. 87, 1926.

⁶ Nutting, P. G.: *The Bleaching Earths*. Ind. and Eng. Chem., Anal. Ed., vol. 4, no. 1, p. 140, 1932.

shown later to consist of montmorillonite and conform to the behavior of typical montmorillonite, which loses a large part of its water below 120° C. and the remainder gradually with rising temperature.⁷ The X-ray data for the Olmstead clay mineral and montmorillonite are practically identical (Fig. 2 and Table IV), the only variations being slight differences in the spacing of a few

TABLE II.
CHEMICAL ANALYSES OF MONTMORILLONITE.^a

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.
SiO ₂ . . .	60.78	58.06	56.20	61.70	55.42	58.82	54.46	56.20	48.60	51.28	50.60
Al ₂ O ₃ . . .	13.83	15.03	15.40	15.11	15.61	15.12	16.84	13.20	20.03	10.56	17.23
Fe ₂ O ₃ . . .	4.36	4.26	4.17	2.67	3.55	3.24	3.36	5.08	1.25	6.76	
FeO . . .	.14	.16	.16	1.96	.20	.73					
MgO . . .	1.85	2.18	1.96	1.67	1.46	1.98	4.84	2.92	5.24	10.40	4.56
CaO . . .	1.19	.53	.47	.85	.94	.55	3.20	1.60	1.72	1.44	3.21
Na ₂ O . . .	.19	.16	.15	.28	Tr	.06					
K ₂ O . . .	1.16	.90	1.13	.98	1.41	1.34					
H ₂ O — . . .	5.18	5.13	6.30	5.36	6.35	4.65	16.10	20.32	21.52	20.28	24.32
H ₂ O + . . .	11.10	13.11	13.25	10.71	14.28	12.52					
TiO ₂ . . .		.35	.45	.23	.46	.44	.80		MnO		
P ₂ O ₅ . . .	.26	.44	.33	.52	.26	.37			.16		
Total . . .	100.04	100.31	99.97	100.03	99.94	99.82	99.60	99.32	98.52	100.72	100.00

- I. Top horizon, Standard pit, Olmstead, Ill.;
- II. Middle horizon, Standard pit, Olmstead, Ill.;
- III. Bottom horizon, Standard pit, Olmstead, Ill.;
- IV. Top horizon, Sinclair pit, Olmstead, Ill.;
- V. Middle horizon, Sinclair pit, Olmstead, Ill.;
- VI. Bottom horizon, Sinclair pit, Olmstead, Ill.;
- VII. Montmorillonite from bentonite, Conejos Quad., Colo.;^b
- VIII. Montmorillonite from bentonite, Quilchena, B. C.;^b
- IX. Montmorillonite, Montmorillon, France;^b
- X. Montmorillonite from fuller's earth, Attapulugus, Ga.;^b
- XI. Montmorillonite, Theoretical composition to satisfy formula (Mg, Ca)O.
Al₂O₃ · 5SiO₂ · 8H₂O with MgO : CaO = 2 : 1

^a The samples of purified mineral in the Olmstead fuller's earth that were analyzed chemically were obtained by thoroughly disintegrating the clay in distilled water, decanting the suspension, removing the clay fraction suspension by means of porcelain filter cones, and drying it at room temperature. A microscopic examination showed that the clay mineral fraction was practically free from impurities. These samples were analyzed by O. W. Rees, Associate Chemist, Illinois State Geological Survey.

^b Ross, C. S., and Shannon, E. V.: *Op. cit.*

⁷ Ross, C. A., and Shannon, E. V.: *Op. cit.*, p. 91.

of the lines. However, these variations are within the limit of accuracy for patterns as diffuse as those yielded by the group of clay minerals to which montmorillonite belongs.⁸ The similarity of the patterns is further indicated by the fact that the intensities

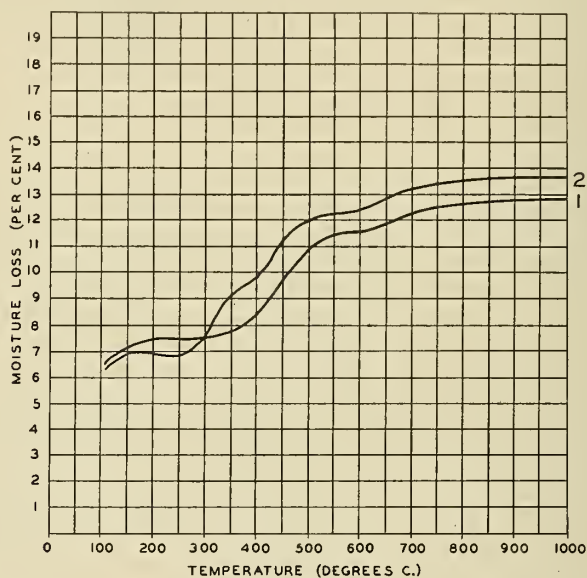


FIG. 1. Dehydration curves for purified clay mineral from Olmstead, Illinois. (See Table III.)

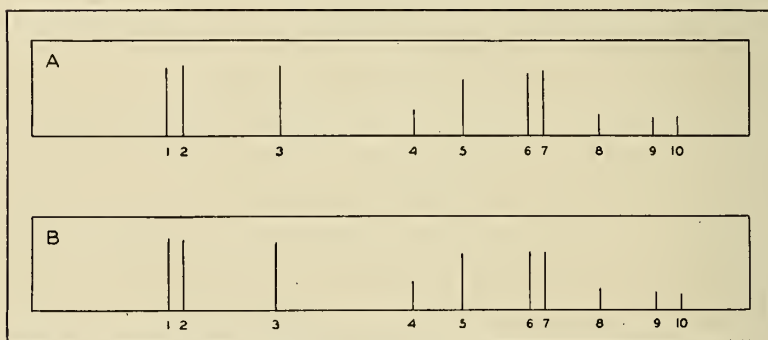


FIG. 2. Diagram illustrating the X-ray diffraction patterns of (A) Olmstead fuller's earth, and (B) montmorillonite, Montmorillon, France. (See Table IV.)

⁸ Kerr, P. F.: *Op. cit.*, p. 164.

TABLE III.

DEHYDRATION OF MONTMORILLONITE FROM OLMSTEAD.^a

^a Determinations by O. W. Rees, Illinois Geological Survey.

Temp. ° C.	Moisture Loss in Per Cent.		Temp. ° C.	Moisture Loss in Per Cent.	
	1	2		1	2
110°	6.39	6.28	485°	10.69	11.90
160°	7.38	6.93	530°	11.25	12.27
250°	7.23	6.87	600°	11.68	12.55
300°	7.50	7.14	650°	11.97	12.88
350°	7.74	9.04	700°	12.23	13.26
375°	7.93	9.45	750°	12.49	13.53
400°	8.28	9.85	1000°	12.78	13.78
450°	9.78	11.42			

1. Upper horizon, Standard Oil Company pit, Ohmstead, Illinois.
2. Upper horizon, Sinclair Refining Company pit, Ohmstead, Illinois.

TABLE IV.

INTERPLANAR SPACING AND INTENSITY OF OLMSTEAD FULLER'S EARTH AND MONTMORILLONITE FROM MONTMORILLON, FRANCE.

Olmstead fuller's earth ^a			Montmorillonite Montmorillon, France ^b		
Line No.	Spacing in Angstrom units	Intensity	Line No.	Spacing in Angstrom units	Intensity
1	4.50	strong	1	4.49	strong
2	4.10	strong	2	4.05	strong
3	2.55	strong	3	2.48	strong
4	1.69	weak	4	1.67	weak
5	1.49	strong	5	1.47	strong
6	1.29	strong	6	1.29	strong
7	1.25	strong	7	1.25	strong
8	1.12	weak	8	1.115	weak
9	1.03	weak	9	1.020	weak
10	.97	weak	10	.976	weak

^a X-ray analyses and calculations (identical for six purified samples) made by Dr. W. A. Sisson, University of Illinois, using a General Electric Company diffraction apparatus with Ka radiation of molybdenum according to method described by W. P. Davey, General Electric Review, vol. 25, pp. 565-580, 1922.

^b Kerr, P. F.: Bentonite from Ventura, California. ECON. GEOL., vol. 26, pp. 164-167, 1931.

of the lines are identical. The X-ray data show no additional lines suggestive of a mixture of other clay minerals than montmorillonite. The optical data likewise indicate that the Olmstead earth contains no clay mineral other than montmorillonite. These data indicate no appreciable vertical or lateral variation in the Olmstead deposits.

In thin section, the Olmstead montmorillonite is light grayish yellow. Much of it occurs in particles too small to permit a determination of shape or size, although it appears to be entirely crystalline. The larger particles are flaky with the acute bisectrix about perpendicular to the larger surface. The flakes are mostly .005 mm. or less, occasionally .01 mm. in diameter, and about a micron thick. The larger flakes have probably increased in size since deposition. A few veinlets of montmorillonite cut across the rock. The montmorillonite in the veinlets differs from that in the balance of the rock by slight differences in the orientation of the mineral particles. These veinlets indicate that there has been some transfer of montmorillonite after the consolidation of the sediment.

Quartz.—Quartz in unsorted grains occurs in small streaks and lenses and irregularly scattered through the clay. They reach a maximum diameter of .12 mm. Those in the lenses and streaks are somewhat larger than the scattered ones. Some of the larger grains are well rounded, but most of them are distinctly angular. With very few exceptions extinction shows that the grains are unstrained. The quartz grains in the lenses fit together perfectly and are commonly cemented by silica, suggesting that since the accumulation of the sediment some of the silica in the quartz grains has been dissolved and redeposited to fill interstitial spaces (Fig. 3, *left*). Some of the quartz grains show distinct embayments of montmorillonite indicating a partial replacement of the quartz by the clay mineral (Fig. 3, *right*).

Muscovite.—Flakes of muscovite constitute 1 to 2 per cent. of the total rock mass. The flakes, many of which are frayed, are of all sizes up to a maximum of .25 mm. in diameter and .02 mm. in thickness. Many of them have been partly altered or replaced

by montmorillonite (Figs. 4 and 5). Some of the larger flakes show montmorillonite along the internal cleavage surfaces where it must have been formed in place. Many of the mica flakes grade into the surrounding montmorillonite, which commonly has the same orientation as the central mass of muscovite. Pseudomorphs of montmorillonite after muscovite also occur.

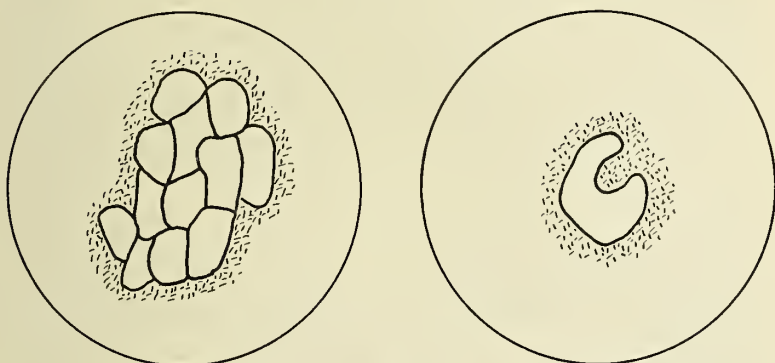
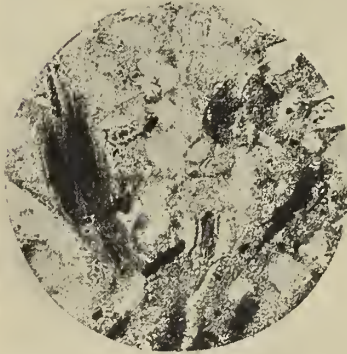
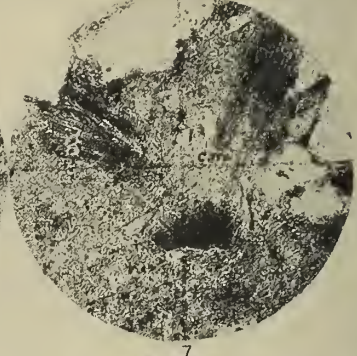
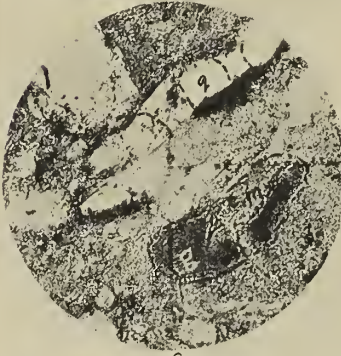
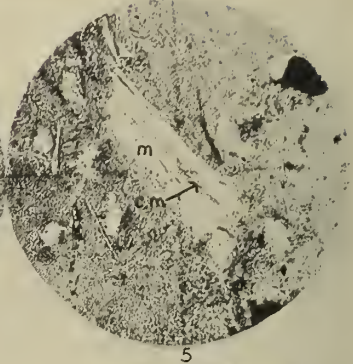
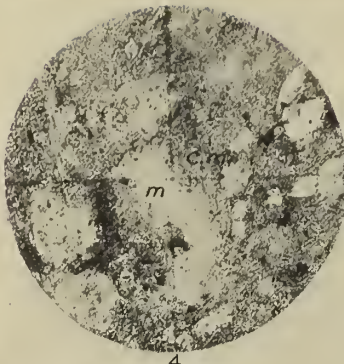


FIG. 3. (Left.) Quartz grains showing mutually accommodating boundaries surrounded by montmorillonite. (Right.) Quartz grain showing an embayment of montmorillonite.

It is not always possible to prove whether the muscovite is altering to montmorillonite or is forming from it, especially in the case of small flakes whose exact identity can not be determined, but it is believed that some of the small flakes of muscovite have formed from the montmorillonite.

Glauconite.—Glauconite, which constitutes 1 to 2 per cent of the rock mass, occurs as rounded grains and irregular masses with a maximum diameter of .1 mm., and is uniformly distributed through the deposit. It varies in color from light-green to dark-green. Two fairly distinct types with intergradations are present. One type is rounded, has a mottled appearance, and under crossed nicols it appears as an aggregate of minute crystalline particles. The other type occurs as irregularly shaped crystalline grains with a pronounced cleavage, creating a micaceous appearance. The average optical constants measured on a series of the latter type of grains from various parts of the deposit are: $2V = 16^\circ \pm$;



(—); $\gamma - \alpha = .025$, $\gamma = 1.615$, $\alpha = 1.590$; pleochroism —Z = yellow-green, X = light yellow-green.

Some grains show alteration to brown limonite, with all gradations from slightly altered grains to limonite pseudomorphic after glauconite. Also many of the glauconite grains appear to have been altered to or replaced by montmorillonite, as suggested by gradation from the glauconite grain to the surrounding montmorillonite, by veinlets and embayments of montmorillonite cutting into and across glauconite grains, and by pseudomorphs of montmorillonite after glauconite. Montmorillonite commonly penetrates glauconite grains that have pronounced cleavage. It is not always possible to determine whether the glauconite is altering to or forming from montmorillonite but in most instances evidence for the alteration of the glauconite is clear. A few grains of glauconite show alteration to both limonite and montmorillonite, in which case the alteration to limonite occurred first, as shown by veinlets and embayments of montmorillonite in limonitic glauconite and by partial pseudomorphs of montmorillonite after limonitic glauconite (Figs. 6-9).

FIGURES 4-9. PHOTOMICROGRAPHS OF FULLER'S EARTH, FROM
OLMSTEAD, ILL.

- FIG. 4. Fragment of muscovite (*m*) grading and altering to montmorillonite (*c.m.*), and showing original muscovite outline. $\times 165$.
- FIG. 5. Montmorillonite (*c.m.*) advancing along cleavage planes of muscovite (*m*). $\times 165$.
- FIG. 6. Grain of glauconite (*g*) whose original boundaries are still discernible (as outlined), partly altered to or replaced by montmorillonite (*c.m.*), and quartz grains (*q*) with mutually accommodating boundaries. $\times 165$.
- FIG. 7. Micaceous glauconite (*g*) altering to montmorillonite (*c.m.*) which is penetrating along cleavage planes. $\times 165$.
- FIG. 8. Fragment of micaceous glauconite (*g*) altering to limonite (opaque) and a limonitic pseudomorph after glauconite (*g*). $\times 165$.
- FIG. 9. Fragment of micaceous glauconite (*g*) altering first to limonite (opaque) and later to montmorillonite (*c.m.*) along cleavage planes. $\times 165$.

Alteration of glauconite to limonite is common but its alteration to a clay mineral is unusual. The evidence presented by the glauconite in the Olmstead fuller's earth suggests two possibilities, first, that the glauconite changes to montmorillonite through an intermediate limonitic stage, and second, that it alters directly to montmorillonite. In support of the first possibility is the occurrence of glauconitic grains partly altered to both limonite and montmorillonite, the montmorillonite evidently succeeding the limonite. Supporting the second possibility is the occurrence of glauconite grains apparently altered directly to montmorillonite. If the limonitic intermediate stage is essential for the change from glauconite to montmorillonite, it must have been completely eliminated from those grains where the glauconite apparently changes directly to montmorillonite. Inasmuch as the iron content of glauconite varies from 16 to 30 per cent.,⁹ whereas the Olmstead montmorillonite contains not more than 4.5 per cent. iron, it is evident that the alteration of glauconite to montmorillonite released an appreciable amount of iron, which is probably the source of the stained streaks and patches in the Olmstead earth.

The constituents of glauconite, other than iron, present no great problem in considering the alteration to montmorillonite. If in published analyses of glauconite, the proportions of iron be reduced to amounts comparable to those of the Olmstead montmorillonite, the proportions of Al_2O_3 , SiO_2 , MgO , CaO , and Na_2O , as correspondingly increased, are in some cases more and in some cases less than in the Olmstead montmorillonite, which suggests that none or only a small amount of some or all of these constituents was added or removed. The K_2O content of the glauconite is appreciably higher than that of the montmorillonite, which indicates that some of it was removed during the alteration, a process that would not be difficult, due to the easy solubility of potash.

Amorphous Silica.—Amorphous silica in irregular scattered particles constitutes 1 per cent. or less of the Olmstead earth.

⁹ Schneider, H.: A Study of Glauconite. Jour. Geol., vol. 25, pp. 289-310, 1927.

Most of the particles are spherical or oval and cellular in structure, indicating an organic origin. A few of those whose origin cannot be determined are prismatic. The particles range up to .1 mm. in diameter and are mostly unaltered but a few of them are partly altered to montmorillonite (Fig. 10).

Other Minerals.—Albite, microcline, kyanite, tourmaline, zircon, rutile, epidote, sillimanite, staurolite, common hornblende, ilmenite, and leucoxene in the order of abundance, are irregularly scattered throughout the Olmstead fuller's earth. They occur in angular unaltered grains .06 mm. or less in size.

Texture.

All of the material composing the Olmstead earth except the amorphous silica and perhaps the secondary limonite is crystalline. The rock is made up of minute flake-like particles of montmorillonite that trend in all directions except around some of the larger mineral grains where it is uniformly oriented. This lack of orientation produces a matted texture which is believed to be responsible for the conchoidal fracture of the rock. The other minerals are scattered through the montmorillonite. The muscovite and micaceous glauconite show no uniformity of orientation.

The dry earth is porous. The individual pores are mostly too small to be seen, but their presence is indicated by the escape of many air bubbles when a fragment is immersed. The total porosity is probably increased by the random orientation of the montmorillonite flakes.

FULLER'S EARTH FROM LOCALITIES OUTSIDE OF ILLINOIS.

Chief Petrographic Features.

Peerless Clay and Metal Company, Creede, Colorado.—This material is composed of about 75 per cent. montmorillonite ($\gamma = 1.507$; $\gamma - \alpha = .02$; (—); $2V$ small), 20 per cent. fragmentary glass, and 5 per cent. quartz, microcline, orthoclase, albite, amphibole, and biotite. The montmorillonite occurs in

crystalline particles a micron or less in size without appreciably uniform orientation. The glass occurs as crescentic and lunar shards, in variable degrees of alteration to montmorillonite, the shard structures being preserved. The material is therefore a bentonite. The grains of quartz, microcline, orthoclase, albite, amphibole, and biotite reach a maximum diameter of .1 mm. and except the quartz are partly altered to montmorillonite (Fig. 11).

Filtrol Company, Tehachapi, California.—This earth is composed almost entirely of montmorillonite ($\gamma = 1.506$; $\gamma - \alpha = .021$; (—); $2V$ small), which occurs in crystalline flakes and particles with a maximum size of .02 mm., fairly well oriented with the long direction parallel to the bedding. Some of the flakes are twisted, suggesting that they may have been produced by the alteration of volcanic glass. The material also contains a very few grains of quartz having a diameter of .03 mm. A very few small round particles appear to be glass but it is not possible to determine positively whether or not the material is a bentonite (Fig. 12).

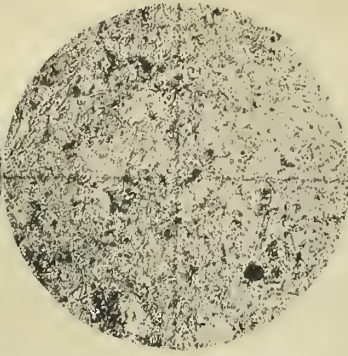
Filtrol Company, Chambers, Arizona.—The material is composed of about 90 per cent. montmorillonite ($\gamma = 1.490$; $\gamma - \alpha = .02$ (—); $2V$ small) and 10 per cent. orthoclase, microcline, albite, amphibole, muscovite, and quartz. The montmorillonite

FIGURES 10-15. PHOTOMICROGRAPHS OF FULLER'S EARTH.

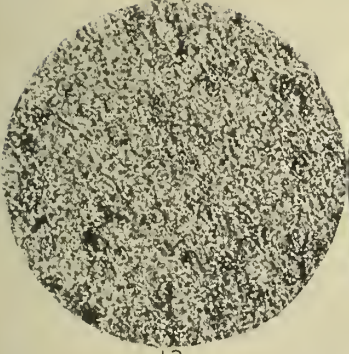
- FIG. 10. Shows in center a mass of amorphous siliceous cellular organic material, partly altered to montmorillonite. Olmstead, Ill. $\times 125$.
- FIG. 11. Shows ash structure indicating bentonite. Creede, Colo. $\times 65$.
- FIG. 12. Shows matted texture produced by relatively large montmorillonite particles. Tehachapi, Cal. $\times 125$.
- FIG. 13. Shows aggregates of montmorillonite (*c.m.*), either pseudomorphic after detrital minerals or original detrital aggregates. Chambers, Ariz. X-nicols, $\times 125$.
- FIG. 14. Shows crescentic, altered, isotropic particle that appears to be an ash fragment but may be organic, so that the bentonitic origin of the earth is uncertain. Ocala, Florida. $\times 125$.
- FIG. 15. Shows well-preserved ash structures indicating bentonite Bath, England. $\times 65$.



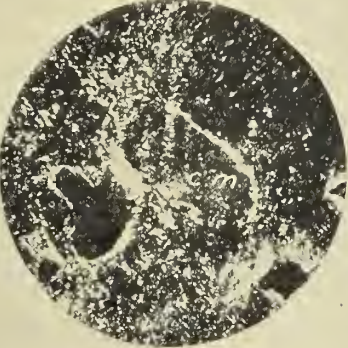
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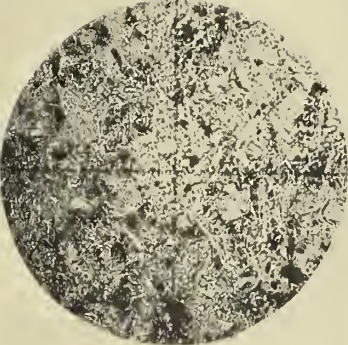
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occurs in crystalline flakes and particles with a maximum size of .005 mm. and without uniform orientation. Thin sections show large, round to rectangular areas of montmorillonite that stand out from the remainder of the matrix. Whether these structures are completely altered original minerals, aggregates formed at the time of accumulation of the sediment, or the result of some post-depositional process, can not be determined. The non-clay minerals are mostly about .06 mm. in size but some of them have a diameter of .5 mm. They show variable degrees of alteration to montmorillonite (Fig. 13).

Superior Earth Company, Ocala, Florida.—This material is composed of about 90 per cent. montmorillonite ($\gamma = 1.524$; $\gamma - \alpha = .022$; (—); $2V$ small) and 10 per cent. fragments of isotropic siliceous material and grains of quartz, albite, and microcline. The montmorillonite occurs in minute crystalline particles a micron or less in size, which show slight uniformity of orientation. Many of the fragments of isotropic material which have a maximum diameter of .12 mm. have a cellular structure suggesting that they are organic remains; others strongly resemble bubble and shard remnants of volcanic glass. They show all degrees of alteration to montmorillonite. The quartz, albite, and microcline grains reach a maximum diameter of .06 mm. They show little or no alteration. The material examined presents strong evidence that this earth is at least in part bentonitic (Fig. 14).

Death Valley, Nevada (Material Received from P. G. Nutting).—This material is composed of about 95 per cent. montmorillonite ($\gamma = 1.514$; $\gamma - \alpha = .023$; (—); $2V$ small) and 5 per cent. unaltered grains of quartz, albite, and orthoclase, with a maximum diameter of .08 mm. The montmorillonite occurs mainly in non-uniformly oriented crystalline particles too small for size or shape determination and in flake-like particles with a maximum diameter of .06 mm. and a fair degree of uniformity of orientation.

Japanese Acid Clay (Material Received from P. G. Nutting).—Only powdered material was available. It is composed of

montmorillonite ($\gamma = 1.512$; $\gamma - \alpha = .023$ (—); $2V$ small).

Terrana earth (Acid-treated German Bleaching Clay).—Only powdered material was available for study. It is composed of montmorillonite ($\gamma = 1.506$; $\gamma - \alpha .024$; (—); $2V$ small) and a very few minute grains of quartz.

English Fuller's Earth from near Bath.—This material is composed of 95 per cent. montmorillonite ($\gamma = 1.502$; $\gamma - \alpha = .021$; (—); $2V$ small) and 5 per cent. quartz, orthoclase, and amphibole, in fragments with maximum diameters of .06 mm. The montmorillonite occurs in crystalline particles varying to .1 mm. in size. The shape of the smaller ones can not be determined, but the larger ones are flaky and show little uniformity of orientation. Orthoclase and amphibole show some alteration to montmorillonite. Glass shards are also present and are excellently preserved. Pseudomorphs of montmorillonite after glass fragments are also perfectly preserved. The earth can be designated as a bentonite (Fig. 15).

Fuller's Earth Company, Midway, Gadsden County, Florida.—This earth is composed almost entirely of montmorillonite ($\gamma = 1.534$; $\gamma - \alpha = .023$; (—); $2V = 8^\circ \pm$), which occurs in crystalline particles too small for size or shape determinations but showing a high degree of uniformity of orientation. A few quartz grains having a diameter of .06 mm. and a few minute flakes of muscovite are also present.

Western Clay and Metals Company, Ivey, Utah.—About 50 per cent. of this material is montmorillonite ($\gamma = 1.507$; $\gamma - \alpha = .022$; (—); ?) occurring in small crystalline particles which show slight uniformity of orientation. Structures indicating that at least some of the montmorillonite has been produced by the alteration of volcanic glass are excellently preserved. The remainder of the rock is composed chiefly of fragments of microcline and sodic plagioclase reaching several millimeters in diameter and partly altered to montmorillonite. Fragments of biotite and grains of ferro-magnesian minerals too highly altered to permit specific identifications are also present. A few grains of quartz occur.

Standard Fuller's Earth Company, Bexar County, Texas.—About 95 per cent. of this material is montmorillonite ($\gamma = 1.514$; $\gamma - \alpha = .022$; (—); $2V$ small), which occurs in crystalline particles and flakes with a maximum size of .02 mm. and little uniformity of orientation. The lack of orientation and the flake-like character of the larger particles produce a matted texture which resembles that produced by the alteration of glass. Angular to round particles of isotropic material reaching a maximum diameter of .04 mm. are concentrated in parts of the rock, where they make up as much as 25 per cent. of the total. These particles are usually too small for a specific determination, but they appear to be amorphous silica of organic origin. A very few grains of quartz having a maximum diameter of .05 mm. are also present. The material may be bentonite.

General Reduction Company, Twiggs County, Georgia.—About 90 per cent. of this earth is montmorillonite ($\gamma = 1.517$; $\gamma - \alpha = .022$; (—); $2V = 10^\circ \pm$), which occurs in crystalline particles and flakes having a maximum size of .005 mm. with uniform orientation. The remainder of the rock is composed of grains of quartz with a maximum diameter of .04 mm., flakes of muscovite with a maximum diameter of .12 mm., and grains of glauconite with a maximum diameter of .04 mm. The flakes of muscovite grade to montmorillonite along their boundaries.

Attapulugus Fuller's Earth Company, Attapulugus, Georgia.—This material is composed of about 95 per cent. montmorillonite ($\gamma = 1.534$; $\gamma - \alpha = .022$; (—); $2V = 10^\circ \pm$) in small crystalline particles uniformly oriented and 5 per cent. of quartz in angular, scattered grains with a maximum diameter of .05 mm.

Floridin Company, Quincy, Florida.—About 70 per cent. of this earth is montmorillonite ($\gamma = 1.532$; $\gamma - \alpha = .021$; (—); $2V$ small), in small crystalline particles some of which have a diameter of .01 mm. They are uniformly oriented. Veinlets and grains of calcite constitute about 20 per cent. of the rock. The calcite grains have a maximum diameter of .5 mm. The remainder of the rock is made up of quartz grains .12 mm. in maximum diameter, flakes of muscovite .12 mm. in maximum

diameter, and grains of glauconite .25 mm. in maximum diameter, irregularly scattered through the montmorillonite.

X-RAY ANALYSES.

X-ray analyses of purified samples of the clay mineral in the earths from Attapulcus, Georgia; Twiggs County, Georgia; Ivey, Utah; and Bexar County, Texas, were made by Dr. W. A. Sisson, University of Illinois. The diffraction patterns and computations are identical with those of typical montmorillonite, which confirms the identifications determined from optical data. The absence of any additional lines in the diffraction patterns indicates that the clay mineral is one definite crystalline mineral and not a mixture of several constituents.

PETROGRAPHIC DATA BEARING ON THEORIES OF DECOLORIZING ABILITY.

Several theories,¹⁰ based on various data, have been advanced to explain the decolorizing ability of fuller's earth, but any worthwhile theory must take into account physical, chemical, and petrographical factors. A study of clays known to have bleaching ability has revealed some petrographic factors that should be considered in the development of such theories.

(1) Generally fuller's earths are made up of crystalline components except for very small quantities of glass and amorphous silica in some earths, and therefore its decolorizing ability cannot be ascribed to the presence of amorphous material.

(2) The clay mineral is the active constituent of the earth, and the other minerals may be regarded as adulterants. Unless the earth is extremely pure, an analysis of the bulk material will not reveal the composition of the active component, and therefore in general will not indicate whether or not an earth has bleaching properties. As the clay mineral is the active constituent, some

¹⁰ Porter, J. T.: Properties and Tests of Fuller's Earth. U. S. Geol. Survey, Bull. 315, pp. 268-290, 1907. Parsons, C. L.: Fuller's Earth. U. S. Bur. Mines, Bull. 71, 36 pp., 1913. Shearer, H. K.: Fuller's Earth Deposits of the Coastal Plain of Georgia. Ga. Geol. Survey, Bull. 31, 1917. Nutting, P. G.: The Bleaching Earths. Ind. and Eng. Chem. Anal. Ed., vol. 4, pp. 139-141, 1932.

earths, notably the English and the Utah earths, are purified before use, and this is one of the reasons why others, such as the Terrana earth, are treated with acid.

(3) All of the fuller's earths described contain montmorillonite. Smectite, which in some textbooks on mineralogy has been considered the constituent of fuller's earth, is identical with montmorillonite.¹¹

However, it has not been established that montmorillonite is the only clay mineral possessing bleaching ability and that therefore all fuller's earths are montmorillonite clays; on the contrary, certain Texas fuller's earths contain a clay mineral similar to but not identical with montmorillonite¹² and other earths not described may contain different types of clay minerals.

It seems certain that crystal structure, cleavage, adsorption ability, base-exchange capacity, chemical composition, etc., of certain clay minerals, notably montmorillonite, give them the property of decolorizing oils or permit them to be activated so that they gain decolorizing ability.

(4) In most of the earths examined the clay mineral particles were too small to be measured but probably were a micron or less in size, although particles having a maximum diameter of several hundredths of a millimeter are abundant in some earths. The larger particles appear to be micaceous, and it is possible that during decolorization the larger flakes split into smaller ones if small particle size is necessary for decolorizing ability. Other clays without bleaching ability contain the same quantity of the same size of other clay mineral particles, so that size of constituent particles does not appear to be a controlling factor although it may be a contributing factor in that it governs the amount of clay mineral easily accessible to the material being decolorized.

(5) The larger clay mineral particles are flake-like and micaceous, so that the smaller ones probably have the same form. In an attempt to account for the properties of bentonite, it has

¹¹ Kerr, P. F.: Montmorillonite or Smectite as Constituents of Fuller's Earth and Bentonite. *Amer. Min.*, vol. 17, pp. 192-198, 1932.

¹² Broughton, M. N.: Texas Fuller's Earths. *Jour. Sed. Petrology*, vol. 2, pp. 135-140, 1932.

been suggested¹³ that the clay mineral particles are probably flakes of colloidal thickness but larger in other dimensions. Examination of the material in thin section provides data agreeing with this conclusion.

(6) Fuller's earth has no characteristic texture. In many thin sections the individual clay particles show no uniformity of orientation whereas in others the uniformity of orientation is almost perfect. In the first case, an appreciable but undeterminable amount of pore space is strongly suggested but in the other case there is no evident porosity. The powdering of the earth before use and the probable disaggregation of the clay fragments during use seem to eliminate texture as an essential factor in decolorizing but it may be a contributing factor insofar as it controls the ease of access to the clay particles.

(7) The decolorizing ability of bleaching clays seems to be independent of their genesis. The Olmstead earth is a near-shore marine sediment, the deposit of the Filtrol Company at Chambers, Arizona, is a terrestrial deposit,¹⁴ and the earth from Ivey, Utah, is a decomposed dacitic breccia underlying conglomerates that are at least in part fluvialite.¹⁵ Some deposits of fuller's earth are produced by *in situ* decomposition of basic igneous rocks.¹⁶ Decolorizing material has been obtained from glacio-lacustrine deposits in Massachusetts.¹⁷

Some fuller's earths have had a bentonitic origin. Other earths do not appear to be bentonites.

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¹³ Wherry, E. T.: Bentonite as a One-dimensional Colloid. Amer. Min., vol. 10, pp. 120-123, 1925.

¹⁴ Tenney, J. B.: The Mineral Industries of Arizona. Ariz. Bur. of Mines, Bull. 129, p. 93, 1930.

¹⁵ Crawford, A. L.: Personal communication.

¹⁶ Miser, H. D.: Developed Deposits of Fuller's Earth in Arkansas. U. S. Geol. Survey, Bull. 530, pp. 207-220, 1913. Roggatt, H. G.: Fuller's Earth in N. S. Wales. Geol. Survey of N. S. Wales, Bull. 14, pp. 15-18, 1924.

¹⁷ Alden, W. C.: Fuller's Earth and Brick Clays near Clinton, Mass. U. S. Geol. Survey, Bull. 430, pp. 402-404, 1910.

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