# ATTAPULGUS CLAY

PAUL F. KERR, *Columbia University, New York City.*

## ABSTRACT

The identity and origin of the clay mineral in the fullers earth from Attapulgus, Georgia, has been studied. Data which have appeared recently in the literature concerning the creation of a new mineral species called "attapulgite" are not verified. X-ray diffraction studies, determination of refractive indices and chemical analyses point to the identity of the clay mineral constituent with montmorillonite.

It is believed that the clay represents an accumulation of weathered montmorillonite derived from the crystalline rocks of the highlands. The field relations of the Attapulgus clay, the structure and texture of the clay, and settling experiments lead to the conclusion that the fullers earth beds were accumulated under shallow water. The suspended clay mineral probably settled slowly and built up a mass of more or less flat-lying flakes oriented parallel to the lamination. The clay was probably later subjected to the minor pressure of overlying sediments.

## INTRODUCTION

The adsorptive or bleaching clay industry in the United States dates from 1893. At that time it was found that clay from deposits in the vicinity of Quincy, Florida (Van Horn, 1911), could be substituted to advantage for German fullers earth. Fullers earth had been discovered in Arkansas before, as reported by J. C. Branner (1913), but the production of the Arkansas deposits turned out to be of minor importance. Since the original discovery in the vicinity of Quincy, the fullers earth production in the Georgia-Florida district (Shearer, 1917) (Sellards, 1909) has become the most important in the United States. The two largest operating plants are located at Attapulgus, Georgia, and Quincy, Florida, where several hundred thousand tons of clay are produced annually. Large clay pits are operated at Midway and Jamieson in Florida, according to Gunter (1931, 1933), and in addition, fullers earth is produced farther north in Georgia (Shearer, 1917) and farther south in Florida (Grim, 1933).

Beds of laminated clay which are generally described as fullers earth are known in many places in the district. Exposures are greenish gray when moist, but where dry surfaces are developed by stripping and cleaning operations, the clay is frequently light gray or almost white. The beds are found in the Alum Bluff Group, of Miocene age (Cushman, 1932) (Simpson, 1932), occurring in the Hawthorn formation. Strata may form individual members of sufficient thickness for mining, or may consist of thin horizontal layers intercalated between sedimentary beds of a sandy or calcareous nature. Younger Miocene beds (Choctawhatchie formation) overlie the various formations of the Alum Bluff Group, and are separated from the latter by a disconformity. Not only the associated

sedimentary beds, but the fullers earth beds themselves may be truncated by the erosion surface. This feature combines with lenticularity to interrupt the continuity in the distribution of the fullers earth strata.



Fɪɢ. 1 (left). A general view of the clay workings at Attapulgus, Georgia, showing the large amount of terrane mined in removing fullers earth. The spoil piles of old workings appear in the picture.
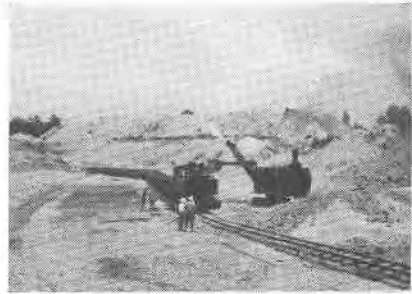
Fɪɢ. 2 (right). Loading fullers earth at Attapulgus, Georgia. A flat lying bank of fullers earth about ten feet in thickness is shown at the right of the shovel. The bed is also exposed on the opposite side of the workings at the extreme left of the view.

The fullers earth of the Georgia-Florida district has long been known to have well recognized decoloring properties for mineral and vegetable oils, and is used in the oil industry in large quantities. Fullers earth has
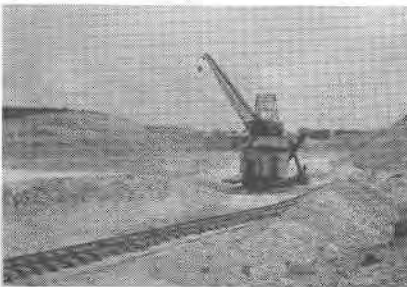


Fɪɢ. 3 (left). A stripped bed of Attapulgus clay ready for mining. The steam shovel rests in a depression which represents an old erosion channel on the top of the fullers earth bed.
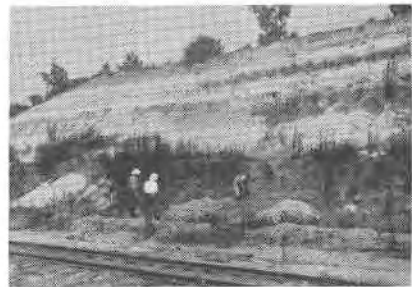
Fɪɢ. 4 (right). Photograph of the fullers earth bed at Attapulgus, Georgia, showing the intercalated sand and clay overburden. The stratum in the foreground about nine feet thick, being cleaned preparatory to taking a sample is fullers earth. A thin streak of precipitated dolomite divides the fullers earth stratum just below the middle.

a high natural efficiency in removing the coloring matter from oil (Nutting, 1933). Oil is allowed to percolate through the clay, during which process a large amount of the coloring matter is removed. Such clays

may be described as naturally active or adsorptive, and are not to be confused with activated adsorptive clays which are acid treated and used in contact filtration. As a rule, the clays which are naturally adsorptive do not respond to acid treatment in suitable degree for use in contact filtration, and the clays which show a high efficiency in the contact process are low in natural adsorption (Nutting, 1932). Two exceptions are worthy of record. A bentonite of natural efficiency, mined at Tehachapi, California, is used in the manufacture of certain types of acid treated clay, according to Kerr and Cameron (1936). Imported acid treated German clay is made by treating a naturally active German fullers earth.

Naturally adsorptive clays are generally marketed under the name *fullers earth*, while acid treated clays are ordinarily marketed under a trade name. Thus far, clays satisfactory for acid treatment have been bentonites, as defined by Ross and Shannon (1926), although many types of bentonite are not satisfactory for acid treatment. The Georgia-Florida clays, although frequently used as standards for comparison in testing the efficiency of a clay for decolorizing purposes, have not as yet been acid-treated on a commercial scale, and are still generally referred to as fullers earths.

Notwithstanding the fact that fullers earth deposits have been worked for many years, and the fullers earth from the Georgia-Florida district has occupied an important position in the field of production of adsorptive clays, there remain many features concerning the nature and behavior of the clay mineral constituent of the fullers earth which merit further study. During the summer of 1936, an opportunity was offered to visit the deposits and collect material for laboratory studies.

Although four deposits were visited,[1] this report is restricted to the clay at Attapulgus, because more time was spent there and a better opportunity was offered to obtain characteristic material. It is felt that a study of the Attapulgus clay is to a large degree applicable to the district, but a more general discussion of the fullers earths throughout the district will be reserved for a later paper.

[1] Deposits operated in the vicinity of Quincy, Jamieson and Midway, Florida.

A number of specimens used in securing $x$-ray diffraction patterns have been obtained through the courtesy of the U. S. Geological Survey. Dr. Clarence S. Ross of the U. S. Geological Survey has kindly reviewed the manuscript of this paper and offered constructive suggestions. Mr. E. N. Cameron of Columbia University has assisted in portions of the optical and petrographic examinations, and Mr. Earl Emendorfer has made a chemical analysis of the Attapulgus clay.

## Coarse Minerals in the Clay

The minerals of the fullers earth deposits may be readily divided into coarser fragmental mineral grains and fine clay material. The coarser fragments include quartz, feldspar, and occasional particles of other silicate minerals. The grains are for the most part angular or subangular, and vary in size from a few microns to about 1 mm. in diameter. The more abundant grains encountered in the sandstone associated with the clay include quartz, alkalic feldspar, sphene, magnetite, leucoxene and zircon. Occasional grains of collophane may be observed. Small fragments are distributed throughout the clay and few areas may be found without detrital material, even in thin sections.

The wide distribution of detrital grains throughout the clay indicates similarity of origin for both the grains and the associated clay. Included sillimanite needles in quartz fragments point to crystalline rocks as the original source.

## Carbonate Layers

Carbonate layers are of frequent occurrence in the strata containing the clay. In one place at Attapulgus, a lenticular layer of dolomite varying from 2 inches to 10 inches in thickness, and 100 feet across, has been shown by drill records to extend through the deposits for 1000 feet. The carbonate in this layer is made up of minute euhedral rhombohedra for the most part from 5 to 10 microns in diameter. The crystals are uniform in size and give the appearance of having been directly precipitated. At least it is hard to imagine such uniform crystallization lacking cementing material or the bond of interlocking grains unless produced by direct precipitation. Lenticular deposits of the type observed might be easily precipitated in shallow marine waters.

## "Attapulgite" or Montmorillonite as the Essential Constituent of Attapulgus Clay

Descriptions have recently been published by Lapparent (1935), in which the clay mineral constituents from Attapulgus, Georgia, and Mormoiron, France, have been compared, and the conclusion reached that

the two are similar hydrous magnesium aluminum silicates warranting description as a separate mineral. The identification has been based upon chemical analysis and $x$-ray diffraction data, and it has been stated that, contrary to the opinion of American authors, the material is not montmorillonite. The name *attapulgite* has been assigned to the mineral (Lapparent, 1936) and a chemical formula derived which indicates an isomorphous series varying between the limits $3SiO_2 2MgO \cdot 4H_2O$ and $5SiO_2 \cdot Al_2O_3 \cdot 6H_2O$. The magnesium end member corresponds to the formula of sepiolite. No known mineral corresponds to the other end member. It is one of the purposes of this paper to review the data available for the identification of the clay mineral from Attapulgus, in the light of recently published descriptions.

Many samples of Attapulgus clay have been examined microscopically and by means of $x$-rays in the course of clay mineral studies over a period of years. Notwithstanding rigorous selection of material in both field and laboratory, and care in the separation of the clay mineral constituent, specimens entirely free from minute microscopic fragments of enmeshed quartz have not yet been secured. $X$-ray diffraction patterns invariably show a few of the more prominent lines due to quartz, superimposed upon an $x$-ray diffraction pattern of montmorillonite.

Numerous $x$-ray diffraction measurements of montmorillonite have been made by different investigators, and a number of these have been recorded in the literature. None of the measurements on record are comparable in accuracy with similar measurements of coarsely crystalline minerals with good reflecting planes. The lines due to montmorillonite are generally too diffused to yield accurate measurements, and too few in number for a wholly satisfactory pattern. Direct comparison of patterns is generally more satisfactory in the identification of montmorillonite than the comparison of computed interplanar spacings with those on record. In the present study and in previous studies of montmorillonite, a standard pattern of montmorillonite has been obtained from specimens from the type locality (Damour and Salvétat 1847). Such material has been available from two sources. Through the courtesy of Dr. Clarence S. Ross, material originally from Montmorillon, France, has been obtained from the U. S. Geological Survey, that was type material received directly from the Museum of Natural History in France. Type material from Montmorillon has also been available from the mineralogical collection of Columbia University.

Early in the course of $x$-ray investigations of the clay minerals, as stated by Bonine (1928), Wherry, Ross and Kerr (1929) reported $x$-ray diffraction patterns of montmorillonite in confirmation of the optical and chemical work of Ross and Shannon (1926). Later Hendricks and

Fry (1930) recorded x-ray diffraction measurements of montmorillonite taken with copper radiation in their study of soil colloids. The measurements of x-ray diffraction patterns of montmorillonite present in bentonite and fullers earth taken with molybdenum radiation were recorded by Kerr (1931, 1932). At about the same time, Kelley, Dore and Brown (1931) published x-ray diffraction measurements of montmorillonite present in soil colloids and in bentonites, obtained with molybdenum radiation. Later Hofmann, Endell and Wilm (1933), in studying the crystal structure and swelling of montmorillonite, gave x-ray diffraction measurements of the mineral taken with copper radiation. Further x-ray diffraction measurements of montmorillonite taken with molybdenum radiation have been recorded by Laudermilk and Woodford (1934). Gruner (1935) in his study of the structural relationships of nontronites and montmorillonite, has published a series of x-ray diffraction measurements taken with iron radiation. Variations in the computation of interplanar spacings, particularly in the case of widely spaced lines, are noticeable in the recorded data. Comparison of the more prominent lines, however, indicates a general agreement in the recorded measurements within the limits of error, when the character of the patterns is considered. Lines and computations considered significant for purposes of comparison are shown in Table 1. In order to make a more definite comparison with the patterns taken with molybdenum radiation, a number of weak lines are omitted, and no reference to comparative intensity is made.

The structure of montmorillonite based on x-ray measurements has been interpreted by Dore as being isometric, and by Hofmann, Endell and Wilm as orthorhombic, Gruner, however, has pointed out that a monoclinic structure seems more likely, as would be suggested by the optical properties and probable affiliation with minerals known to be monoclinic. In the case of diffused reflections, usually obtained from atomic planes of montmorillonite, and in the absence of crystallographic data, it would seem that any structural interpretation with the information now available would be largely tentative.

The relationship with sepiolite suggested by Lapparent (1935) is of interest, and it has been considered worthwhile to obtain x-ray data on sepiolite for purposes of comparison. Specimens of sepiolite available for study from Hrubschnitz, Moravia; Bear Mt., N. M., and Spain, give identical x-ray diffraction patterns, but the patterns in each case fail to agree with montmorillonite. This agrees with the result reported by Ksanda (Foshag and Woodford, 1936), who has also compared patterns of montmorillonite and sepiolite and has found that patterns of the two minerals differ. Also Schaller (1936) has pointed out after a

| X-ray Diffraction Measurements of Montmorillonite. | | | | |
|---|---|---|---|---|
| Hofmann,[*] Endell & Wilm | Hendricks & Fry | Gruner | Dore | Kerr |
| Cu K$\alpha$ Å | Cu K$\alpha$ Å | Fe K$\alpha$ Å | Mo K$\alpha$ Å | Mo K$\alpha$ Å |
| 15.2 | | 15.0 | | |
| 4.32 | 4.493 | 4.45 | [†]5.0 | 4.49 |
| | | | [†]4.4 | 4.05 |
| 2.50 | 2.551 | 2.535 | 2.56 | 2.48 |
| | | | 1.69 | 1.67 |
| 1.47 | 1.491 | 1.494 | 1.495 | 1.47 |
| 1.27 | 1.286 | 1.285 | 1.295 | 1.29 |
| 1.22 | 1.238 | 1.241 | 1.25 | 1.25 |
| 1.11 | | | | 1.115 |
| 1.02 | | | | 1.020 |
| 0.966 | | | | 0.976 |

[*] Computed from recorded sin $\theta$.

[†] Measurements probably too large by about 0.5 A.U.

review of 56 chemical analyses that there is only one sepiolite which has the formula $2MgO \cdot 3SiO_2 \cdot 4H_2O$.

Saponite appears from x-ray patterns to be isomorphous with montmorillonite. The arrangement of lines indicating structural resemblance, but differing in spacing, is striking. Similar x-ray diffraction patterns of saponite have been obtained from material from the Kearsarge and Ahmeek mines (Palache & Vassar, 1925), secured through the courtesy of Professor Charles Palache of Harvard University; from a magnesian bentonite occurring near Needles, California, furnished by Mr. Frank Sanborn of the California State Mining Bureau; and from saponite from Montreal, described by Graham (1918). The interplanar spacings for saponite, nontronite and montmorillonite (or beidellite), members of the montmorillonite group, are given in Table 2. The magnesian clay mineral from Hector, California, described by Foshag and Woodford (1936), also falls in this series but agrees[2] so closely with the spacings for nontronite that the same values are recorded for each. This similarity in x-ray diffraction measurements, however, does not imply chemical similarity, since in this respect the Hector clay differs widely from nontronite.

Drawings of x-ray diffraction patterns of montmorillonite, nontronite

[2] Specimen kindly supplied by Dr. Clarence S. Ross of the U. S. Geol. Survey.

and saponite are shown in Figure 5. Care has been taken to reproduce the *x*-ray lines faithfully both in relative position and in intensity.
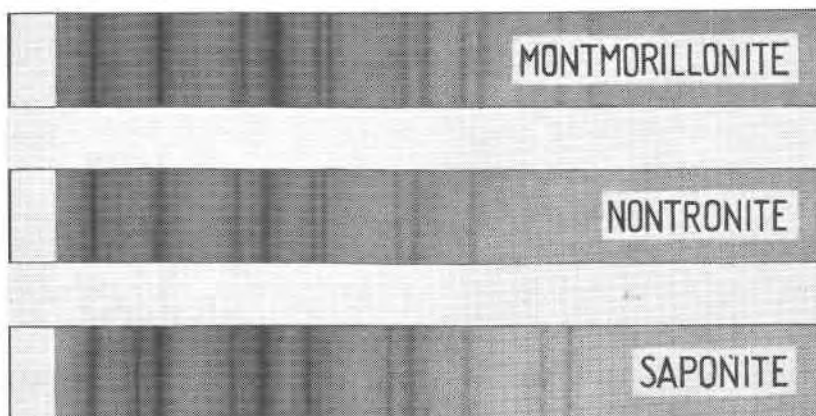


FIG. 5. Drawing of *X*-ray diffraction patterns showing variations in both intensity and spacing to scale.

TABLE 2

| Usual Relative Intensity | Saponite A.U. | Hector Clay A.U. | Nontronite A.U. | Montmorillonite (or Beidellite) A.U. |
|---|---|---|---|---|
| | | | *X*-ray Diffraction Measurements in the Montmorillonite Group.*| |
| S | 4.51 | 4.51 | 4.51 | 4.49 |
| M | 4.06 | 4.05 | 4.05 | 4.05 |
| M | 3.01 | | | |
| S | 2.54 | 2.54 | 2.54 | 2.48 |
| W | 2.45 | 2.45 | 2.45 | |
| M | 1.74 | 1.73 | 1.73 | 1.67 |
| S | 1.52 | 1.49 | 1.49 | 1.47 |
| M | 1.32 | 1.31 | 1.31 | 1.29 |
| M | 1.29 | 1.28 | 1.28 | 1.25 |
| W | 1.155 | 1.145 | 1.145 | 1.115 |
| W | 1.050 | 1.040 | 1.040 | 1.020 |
| M | 1.000 | 0.990 | 0.990 | 0.976 |

* The line at 3.01 A.U. is usually absent or very weak in patterns of montmorillonite, beidellite or nontronite; Mo K$\alpha$ radiation. Letters indicating relative intensities of lines:
S: strong          M: moderate          W: weak

In the description of attapulgite, *x*-ray diffraction measurements are furnished for 10 lines (Lapparent 1935). Four of these lines may be shown to agree within the limits of error with *x*-ray diffraction lines of mont-

morillonite. Four agree with lines due to quartz, according to the meas-
urements recorded by Harrington (1927), and confirmed in the present
study. Two lines may be due to both quartz and montmorillonite. A
likely interpretation of the x-ray data is shown in Table 3.

The chemical analysis given by Lapparent is normal for selected
Attapulgus clay. For comparison, analyses by Shannon (1926) and Mr.
Earl Emendorfer of Columbia University are shown in Table 4.

The analyses indicate that magnesium may be in excess of the amount
usually present in montmorillonite. Since Mg may proxy for Al in the
montmorillonite group, this excess over the amount in normal mont-
morillonite may be expected.

TABLE 3

An Interpretation of X-ray Diffraction Data for "Attapulgite"

| Interplanar Spacings "Attapulgite" A.U. | Interpretation of Planes Causing Reflections | |
|---|---|---|
| 4.3 | Quartz (4.53) and | Montmorillonite (4.49) |
| 3.25 | Quartz (3.32) | |
| 2.55 | | Montmorillonite (2.48) |
| 2.15 | Quartz (2.12) | |
| 1.8 | Quartz (1.815) | |
| 1.67 | Quartz (1.665) and | Montmorillonite (1.67) |
| 1.49 | | Montmorillonite (1.47) |
| 1.37 | Quartz (1.378) | |
| 1.29 | | Montmorillonite (1.29) |
| 1.25 | | Montmorillonite (1.25) |

The $P_2O_5$ in the analyses is probably due to the presence of a small
amount of collophane. Scattered grains of rutile or ilmenite may account
for the $TiO_2$ reported. The small amount of $CO_2$ may be due to traces
of calcite in the sample analyzed. Probably a small portion of the $SiO_2$,
perhaps 3% to 5%, is due to quartz. The alkalies may belong to the
montmorillonite, since small amounts are frequently reported.

It seems likely that montmorillonite is responsible for most of the
silica, alumina, iron oxide, magnesia, lime and water reported in the
analyses. Analyses of montmorillonite from Montmorillon, France, are
shown in Table 5.

The indices of refraction of the Attapulgus clay fall within the usual
range for montmorillonite, as previously determined by Ross (1926)
and as confirmed in the present study. Indices of refraction of the mont-

TABLE 4

Chemical Analyses of Attapulgus Clay

|  | Emendorfer | Lapparent | Shannon |
|---|---|---|---|
| Silica | 53.42 | 53.64 | 51.28 |
| Titania | 0.52 | 0.60 | |
| Alumina | 10.06 | 8.76 | 10.56 |
| Ferric oxide | 3.40 | 3.36 | 6.76 |
| Ferrous oxide | 0.18 | 0.23 | |
| Manganous oxide | 0.02 | 0.03 | |
| Magnesia | 9.16 | 9.05 | 10.40 |
| Lime | 1.29 | 2.02 | 1.44 |
| Soda | 0.02 | 0.83 | |
| Potash | 0.64 | 0.75 | |
| Phosphoric anhydride | 0.12 | 0.79 | |
| Water above 110°C. | 9.42 | 10.89⎫ | |
| Water at 110°C. | 11.83 | 9.12⎭ | 20.28 |
| Carbon dioxide | 0.10 | | |
| Chlorine | 0.02 | | |
| Sulphuric anhydride | 0.04 | | |
| | 99.96 | 100.07 | 100.72 |

TABLE 5

Chemical Analyses of Montmorillonite from Montmorillon, France

|  | Salvétat | Shannon |
|---|---|---|
| Silica | 49.40 | 48.60 |
| Alumina | 19.70 | 20.03 |
| Ferric oxide | 0.80 | 1.25 |
| Lime | 1.50 | 1.72 |
| Magnesia | 0.27 | 5.24 |
| Manganous oxide | | 0.16 |
| $(K, Na)_2O$ | 1.50 | |
| $H_2O$ | 25.67 | 21.52 |
| | 98.84 | 98.52 |

morillonite in Attapulgus clay were carefully determined by Mr. E. N. Cameron of Columbia University, on air-dried material as follows:

$$\alpha = 1.511 \pm .003 \qquad \gamma = 1.532 \pm .003 \qquad \gamma - \alpha = .021$$

This agrees with the determination by Grim (1933) who gives $\gamma = 1.534$ and $\gamma - \alpha = .022$. The writer has also made index determinations in agreement with the above: $\alpha = 1.510 \pm .003$; $\gamma = 1.533 \pm .003$; $\gamma - \alpha = .023$.

While the magnesium content of Attapulgus clay is greater than is normal for montmorillonite, and the indices of refraction are possibly slightly high, it would not seem feasible to consider the clay mineral constituent of the Attapulgus clay as a distinct mineral with the data now available.

## MICROSCOPIC STRUCTURE OF THE CLAY

Varying degrees of completeness of optical orientation have been observed in all laminated sections of the Attapulgus clay examined, some thin sections showing a much more definite orientation effect than others. Sections of the clay cut parallel to the lamination differ in mass birefringence from sections cut at right angles. It is possible to obtain
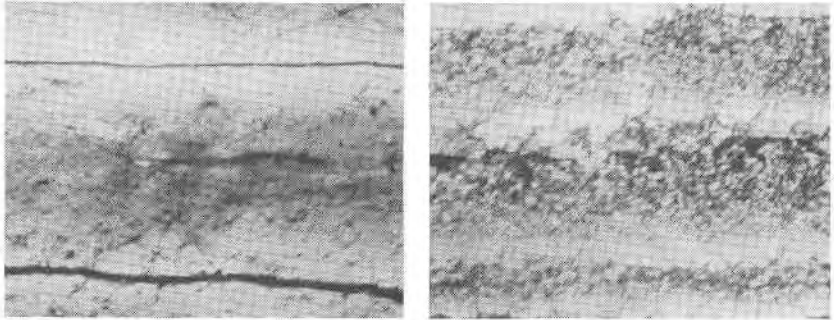


FIG. 6 (left). Attapulgus clay cut perpendicular to the lamination. Thin section photomicrograph, x-nicols ($\times$50). The closely matted clay crystals are sufficiently parallel in orientation to produce uniformity of illumination between crossed nicols. Slight variations in antisotropism may be noted in areas about midway between the laminae.

FIG. 7 (right). Attapulgus clay settled in fresh water. Thin section photomicrograph, x-nicols ($\times$48). The layers in the photomicrograph are due to the rhythmic structure developed by repeated additions of material in forming the filter cake. Individual layers of fine grained material compare favorably in uniformity of orientation with the orientation in the natural clay.

biaxial interference figures from the matted mass of minute montmorillonite crystals in thin sections cut parallel to the lamination. As would be expected, these sections show little or no birefringence, observed double refraction being limited to occasional crystals of random orientation, or occasional crystals not quite parallel to the plane of lamination. Sections cut at right angles to the plane of lamination (Fig. 6) show maximum birefringence, and have a variable extinction angle, which averages about 10° to the lamination for the slow ray.

It is believed that the orientation is induced by settling in still water.

It seems likely that the clay particles, in the form of minute flakes, fall in layers. Flakes in the layers not only orient themselves parallel to the surface on which they fall, but also tend to orient themselves parallel to one direction in the plane of the layer. The effect produced amounts to building up a mass of minute flakes of approximately parallel orientation, having to a large degree the properties of a single crystal. In order to obtain optical properties with the microscope, Grim (1934) has allowed montmorillonite to settle in water and build up an oriented cake on a glass slide. The dimensions of the flakes, and the completeness with which the suspended clay material has been broken down into individual crystal units, probably have much to do with the effect. Crystals of montmorillonite are normally so thin that the term *one-dimensional colloid* has been suggested by Wherry (1925).

Several suspensions of Attapulgus clay have been made in the present study, and the suspensions have been collected on a filter paper, a cake of sufficient thickness being built up to allow cutting thin sections normal and parallel to the lamination after drying. A photomicrograph of a thin section of clay collected on the filter paper of a Buchner filter from a suspension in fresh water is shown in Fig. 7. The section is normal to the lamination, and the banding is due to the addition of repeated layers with the separation of finer and coarser particles on settling.

In salt water the clay settles more rapidly but the orientation is not so good (Fig. 8). Pressure applied to the cake formed in salt water increases the orientation effect. Pressure applied to the fresh water cake in a vise while the material is still moist produces packing with pronounced orientation (Fig. 9).

As a result of these experiments, it would seem that settling combined with moderate pressure could account for the formation of the structure in the Attapulgus clay. It is unlikely that the beds have been under any great load, since the overlying strata are inconsiderable. The orientation effect due to settling plus pressure in a vise is about as pronounced as the orientation effect in the natural clay, hence it may be assumed both may contribute to the structure.

Kindle (1932), in describing experiments with the settling of bentonite in water, observed that brine solutions would accelerate the settling and proposed the following interpretation: "This experiment illustrates the possibility that sea water entering a lake near sea level under the special conditions of an exceptionally high tide and extending itself as a separate sheet of salt water would, through the acceleration of settling always produced in very fine sediments by the action of salt, cause the development of a distinct layer along the plane temporarily

occupied by the salt water . . . sea border lakes afford opportunities for the interlamination and interfingering of saline and fresh-water sediments.'' The Georgia-Florida region would appear to offer an ideal illustration of the type of deposition described by Kindle. On the other hand, material allowed to settle slowly in fresh water more nearly duplicates the structure observed in the clay. The imitation is even better when pressure is applied to the settled material. While it would appear that settling and pressure were both effective, the structure suggests that the clay was deposited in fresh water, rather than salt water.
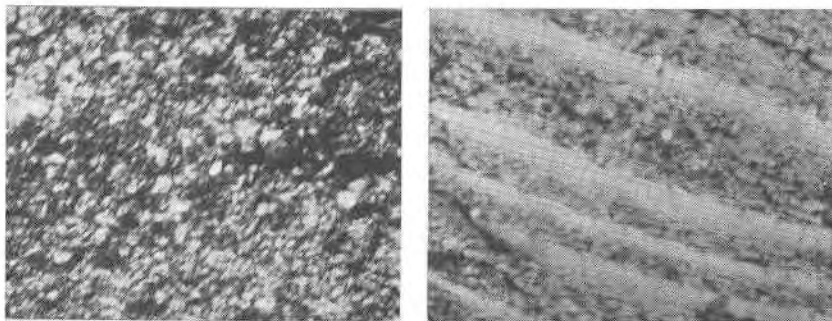


Fig. 8 (left). Attapulgus clay settled in salt water. Thin section photomicrograph, x-nicols (×50). This material shows but a slight tendency to uniformity in orientation. This material settles so rapidly that stratification of the filter cake due to sorting observed in the fresh water settled clay does not develop.

Fig. 9 (right). Attapulgus clay settled in fresh water and pressed. Thin section photomicrograph, x-nicols (×50). The pressure tends to improve the uniformity of orientation.

## ORIGIN OF THE ATTAPULGUS CLAY

The Hawthorn formation in which the Attapulgus clay occurs contains both continental and marine fossils in close proximity to the fullers earth. At Midway, Simpson (1932) has described fossil land mammals which occur both above and below the fullers earth stratum. Cooke (1929) and others have mentioned the occurrence of *Ostraea* and other marine fossils in sandstone strata associated with the fullers earth. Presumably the Hawthorn formation in the vicinity of the fullers earth occurrences represents transitional conditions from marine to continental.

The detrital minerals in the clay, obtained by washing the samples, and the included minerals in the sandy lenses, point to the well-known area of crystalline rocks to the northward as a likely source for the de-

trital constituents. Since these beds were first described, it has been customary to relate their accumulation to the erosion of the crystallines of the highlands. Recent observations making use of a slightly different technique lead to interpretations in accord with earlier conclusions. This study is more concerned, however, with the role of montmorillonite in the process.

The uniformity of the clay mineral in the Attapulgus clay, and its wide distribution, suggest uniformity of the material deposited. The variable crystalline rocks of the highlands, if unaltered and deposited directly, could hardly be relied upon to furnish material of such uniform nature over wide areas. It would seem more likely that the clay of the lowlands represents an accumulation of a uniform product of alteration or weathering, transported by water and deposited on the old Florida peninsula when the coastal plain sediments were being accumulated.

In view of the widespread occurrence of montmorillonite under a variety of conditions, a brief review of the various origins of the mineral is worthy of consideration, particularly with respect to the occurrence at Attapulgus. Montmorillonite has been reported under conditions suggesting hydrothermal origin. It is probably best established as an alteration product of volcanic glass. It has also been considered to be a product of surface weathering.

Montmorillonite has been found in pegmatites in a number of places. Ross and Shannon (1926) mention such occurrences. Brush and Dana (1880) described montmorillonite from Branchville, associated with soft, partially kaolinized cymatolite and coating cleavage surfaces of partially altered spodumene. A specimen from Branchville in the Egleston Collection, Columbia University, contains montmorillonite as a coating on feldspar. Through the courtesy of Mr. John W. Radu, a specimen of a pink clay from a cavity in a pegmatite at Mt. Mica, Maine, has been secured. The $x$-ray diffraction pattern of this mineral agrees with the $x$-ray diffraction pattern of montmorillonite.

Ewell and Insley (1935) prepared synthetic beidellite by treatment of mixtures of alumina and silica at 350° and 390°C. The beidellite was identified by means of $x$-rays. Montmorillonite has been produced synthetically by Noll (1936) under conditions approaching hydrothermal crystallization in nature. Magnesium hydroxide, aluminum hydroxide, silicic acid and water, confined in a nickel-chromium steel bomb 15 to 24 hours at 300°C. and 87 atm., produced material which Noll described as montmorillonite.

The origin of montmorillonite by alteration of volcanic glass deposited under marine conditions appears fairly certain. Several examples may

be found in the bentonite layers of the Monterey (or Modelo) formation of California (Kerr, 1931). Foraminiferal and diatomaceous sediments of great thickness above and below the ash stata point to the deposition of the ash under marine conditions. Relict shards in the bentonite indicate that the alteration to clay followed the deposition of the ash. Evidence is lacking as to whether alteration occurred before or after the deformation of the enclosing sediments.

Unaltered ash, however, occurs at Lompoc, California, in less deformed strata of the Monterey formation, according to Arnold and Anderson (1907). In the diatomite beds at Lompoc, gray volcanic ash occurs interbedded with diatomite in a thin layer about four inches thick. Samples were collected by the writer on a visit to the deposits several years ago. Megascopically, fragments are coarse and granular. Under the microscope, they are clear, transparent and isotropic with $n = 1.504$, which according to George (1924) would indicate a rhyolitic ash.

The occurrence of unaltered ash in moderately deformed strata at Lompoc, and of bentonite in highly deformed and crushed strata at Ventura, both in thick marine Miocene sediments, suggests that local conditions subsequent to deposition may have favored the alteration of the Ventura material. Sulphur bearing adjacent or overlying strata, which occur in the Ventura region, may have provided sulphuric acid responsible for the alteration. The broken condition of the strata would accelerate this action.

Wherry (1917) has described clay derived from water-laid volcanic dust, evidently a montmorillonite clay, occurring in a wide area encircling the southern Black Hills of South Dakota. It was Wherry's impression that the dust was altered due to the accompanying gases, including no doubt hydrochloric acid, sulphur dioxide and other chemically active gases from volcanic emanations. However, Wherry mentioned the abundance of gypsum derived from the alteration of calcite by solution of pyrite in overlying shales. Such action is suggested as offering perhaps a more likely agency for alteration of the volcanic glass.

A significant microscopic feature of the Attapulgus clay is the absence of relict structures indicative of volcanic origin. A large number of thin sections of fullers earth from Attapulgus have been examined without revealing a single feature such as a shard, a flow line, a lithic fragment, or some other feature suggestive of volcanic origin.

Montmorillonite has been recorded as a possible product of weathering on a number of occasions. Laudermilk and Woodford (1934) have described montmorillonite being formed from a pegmatite under conditions which they considered to represent weathering. Hendricks and Fry (1930), Kelley, Dore and Brown (1931), and others have pointed to the

likelihood of montmorillonite as a constituent of soil colloids. These factors indicate the role of montmorillonite in weathering.

It seems possible to conclude that the Attapulgus clay represents an accumulation of montmorillonite as a weathering product resulting from the decomposition of certain mineral constituents of the crystalline rocks of the highlands. The product of decomposition has been transported as deposited in shallow water along the coast in Miocene time. Although the clay is primarily composed of montmorillonite, it is not bentonite. Commercially a fullers earth, and containing montmorillonite as the base mineral, the clay probably represents a water-deposited accumulation of a weathering product. If the assumptions of Kindle may be applied in this case, the clay was accumulated in salt water. Limited settling experiments, however, would point toward the slower settling in fresh water.

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