# Fuller's Earth and Other Industrial Mineral Resources of the Meigs-Attapulgus-Quincy District, Georgia and Florida

GEOLOGICAL SURVEY PROFESSIONAL PAPER 828

# Fuller's Earth and Other Industrial Mineral Resources of the Meigs-Attapulgus-Quincy District, Georgia and Florida

*By* SAM H. PATTERSON

GEOLOGICAL SURVEY PROFESSIONAL PAPER 828

*A summary of the general and economic geology of the major fuller's earth-producing district in the United States*

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1974

UNITED STATES DEPARTMENT OF THE INTERIOR

ROGERS C. B. MORTON, *Secretary*

GEOLOGICAL SURVEY

V. E. McKelvey, *Director*

Library of Congress catalog-card No. 74-600053

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 – Price $2.40 (paper cover)
Stock Number 2401-02503

# CONTENTS



# ILLUSTRATIONS



# TABLES

# FULLER'S EARTH AND OTHER INDUSTRIAL RESOURCES OF THE MEIGS-ATTAPULGUS-QUINCY DISTRICT, GEORGIA AND FLORIDA

By Sam H. Patterson


## ABSTRACT

The Meigs-Attapulgus-Quincy district, Georgia and Florida, has been the leading producer of fuller's earth in the United States since 1895. The deposits occur in discontinuous beds and lenses in the Hawthorn Formation of middle Miocene age. The fuller's earth, in the vicinities of Attapulgus, Ga., and Quincy, Fla., in the southern part of the district, consists mainly of palygorskite (attapulgite of older usage) but contains minor quantities of montmorillonite and nonclay mineral impurities, including quartz, dolomite, calcite, phosphate pellets, feldspar, and miscellaneous heavy minerals. Kaolinite occurs in the upper parts of deposits under shallow overburden, and it apparently has formed by weathering of montmorillonite, which, in turn, weathers from palygorskite. The deposits in the northern part of the district are mainly montmorillonite, but they also contain some palygorskite and sepiolite, abundant diatoms, and several of the nonclay minerals that are present in deposits in the southern part of the district.

The fuller's-earth deposits apparently formed in very shallow marine lagoons or tidal flats. The magnesium in palygorskite, sepiolite, montmorillonite, and dolomite apparently came from evaporating sea water. The silica and aluminum in the clay minerals, which apparently formed in place, probably were introduced by streams, as there is very little evidence to support the theory that volcanic ash was the major parent material of the fuller's earth.

Industrial minerals other than fuller's earth that are now mined in the district include silica sand, construction sand and gravel, and raw materials for common brick. Many years ago, small quantities of limestone and dolomite were dug for use in making portland cement and building stone, and a carload or two of phosphate rock was shipped from one locality.


## INTRODUCTION

Extensive deposits of fuller's earth are present in Miocene sedimentary rocks in southwestern Georgia and northern Florida. The fuller's earth and other industrial mineral deposits in a large area, herein referred to as the Meigs-Attapulgus-Quincy district (fig. 1), were investigated intermittently by the U.S. Geolocial Survey during the period 1963-69. This large district covers all of Grady County and most of Decatur and Thomas Counties, Ga., and all of Gadsden County and part of Leon County, Fla. Small parts of several other Georgia and Florida counties are also within the arbitrary boundaries of the district.

The Meigs-Attapulgus-Quincy district has been the leading producer of fuller's earth in the United States since it was first mined here in 1895. The fuller's earth produced in this district is prepared for market in eight plants. The principal uses are for drilling mud and for granules that absorb many types of undesirable materials, such as oil, grease, and chemicals, from the floors of many types of installations; it is also used for animal litter, soil conditioner, and as an ingredient in many types of fillers, extenders, carriers, diluents, bleaching materials, and other products.

The term "fuller's earth" is based on use, and it has no compositional meaning. Its origin dates into antiquity; it was first applied to fine-grained earthy materials used in fulling wool. More efficient materials have long been used in preparing wool, and the term's meaning has undergone several changes because the fine-grained materials similar to those originally used in fulling have been used for other purposes.

The Meigs-Attapulgus-Quincy district is in a region where there has been much difference of opinion among geologists concerning the extent, thicknesses, and regional relationships of stratigraphic units, the use of stratigraphic names, and the interpretation of geologic structure. The principal reason for these differences is the failure of geologic studies to provide adequate detailed information on lithologic and stratigraphic relationships, because of unfavorable geologic factors. Most surficial rocks are thoroughly weathered, and large areas are blanketed by residuum. Many of the outcrops in sinkholes and streambeds that were observed by the early geologists working in the area are now covered by sediment fill or water. The sediment fill, as noted by Cooke (1943, p. 88), has resulted from the deposition of material eroded from the cultivated uplands and, in places, from man's efforts to control erosion. The water cover is mainly the artificial reservoirs, such as Lake Talquin and Jim Woodruff Reservoir. Not only are exposures limited, but the rocks are characterized by vertical and lateral gradation of rock types. These gradational relationships make formational boundaries and key horizons on which to base structural interpretation difficult to recognize and trace for more than a few miles. Still another unfavorable factor is the extensive solution of carbonate rock. The

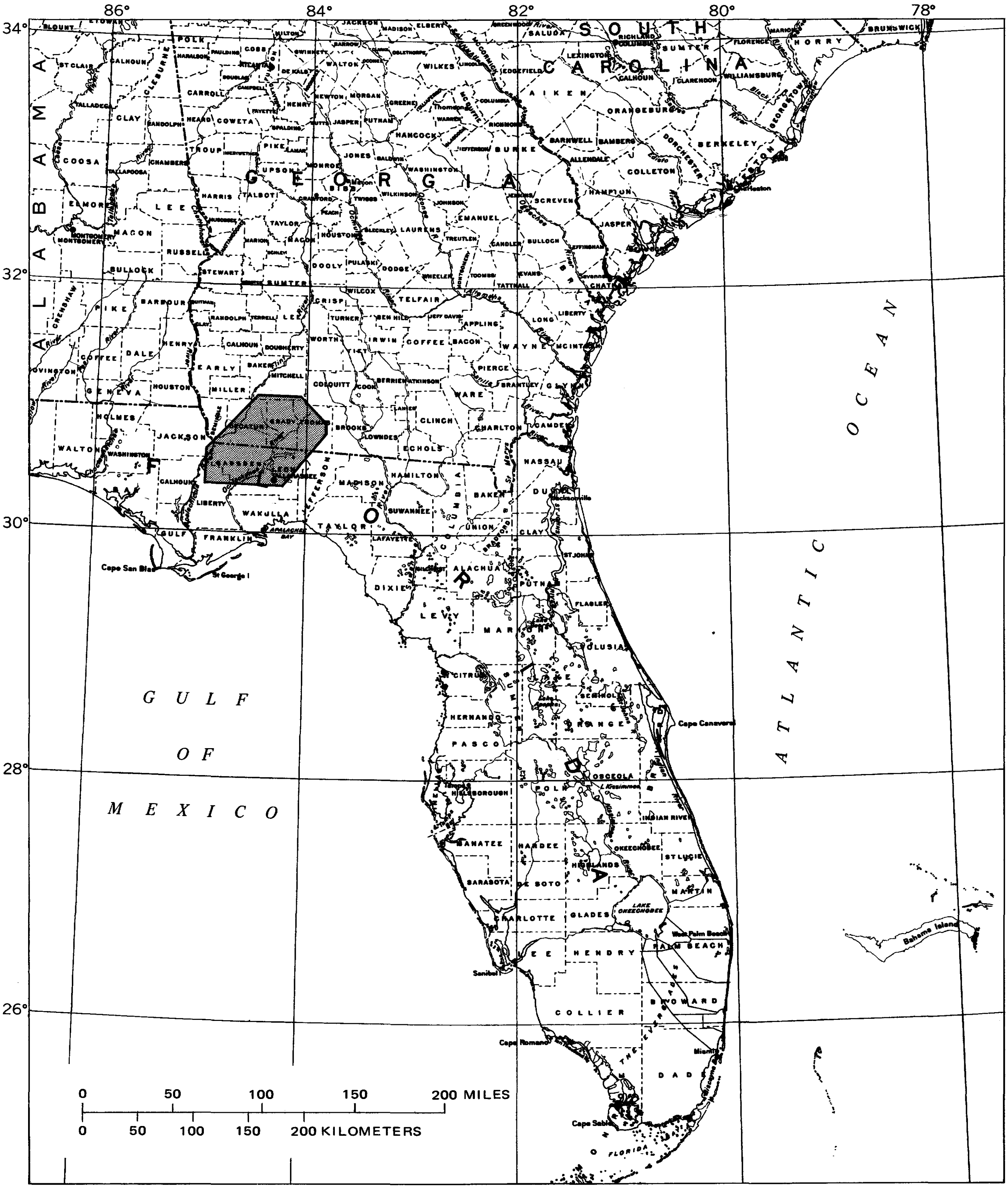



FIGURE 1.—Location of Meigs-Attapulgus-Quincy district, Georgia and Florida.

downward displacement of beds resulting from the solution of underlying rocks makes it difficult to correlate rock units and can easily be misattributed to tectonic forces. Because of all these factors, the extent of the formation containing the fuller's earth can be determined only be geologic inference (pl. 1).

Much information can be obtained, however, as was done in this investigation, by studying all surface exposures and well cuttings, cores, and well logs. The best exposures are in scattered roadcuts, strip mines, quarries, sinkholes, and streambeds. A great deal of information was gained by studying cuttings from water wells in the sample library of the Georgia Department of Mines, Mining and Geology, and well cuttings and cores at the Florida Bureau of Geology. Though these two sample libraries are reasonably complete, many gaps remain, and that lack of adequate subsurface data in critical areas is one of the major roadblocks to understanding the geology of the Meigs-Attapulgus-Quincy district.

## ACKNOWLEDGMENTS

Many geologists and company officials aided the author in carrying out the investigations leading to this report. Dr. R. O. Vernon, former State Geologist of Florida, permitted access to the well-sample and drill-core library at the Florida Bureau of Geology and made available office space for the study of the cuttings and cores. The author also benefited considerably from discussions with Dr. Vernon, Mr. Charles W. Hendry, Jr., present Director of the Florida Bureau of Geology, and J. William Yon, Jr., and Harbans S. Puri, geologists with that bureau. Dr. A. S. Furcron and Mr. Jesse W. Auvil, Jr., both of whom served as Director of the Georgia Department of Mines, Mining and Geology, during the time the work was done, granted use of facilities in their department. Mr. Sam M. Pickering, Jr., of the Georgia Department of Mines, Mining and Geology, visited the author for 2 days in the field and provided a boat and motor for a float trip down one of the headwaters of the Aucilla River to examine outcrops of Miocene age.

Stephen M. Herrick, Robert C. Vorhis, and Harlan B. Counts of the U.S. Geological Survey, Atlanta, Ga., helped the writer in many ways. Counts and Herrick allowed the use of laboratory and office facilities for studying well cuttings in the sample library of the Georgia Department of Mines, Mining and Geology. Herrick aided the author in recognizing stratigraphic units and key Foraminifera in well cuttings and samples from outcrops and permitted the use of many of his unpublished well logs in working out the stratigraphy and structure of the Meigs-Attapulgus-Quincy district. Vorhis spent 3 days with the author in the field and gave considerable assistance in the recognition of stratigraphic units.

John W. Hosterman of the U.S. Geological Survey aided the author in augering deposits in Georgia. Dr. C. E. Weaver of the Georgia Institute of Technology discussed many problems related to mineralogy and origin of the fuller's-earth deposits with the author. Dr. B. F. Buie of the Florida State University and Dr. L. R. Gremillion, while a graduate student at that university, helped during the investigations.

Representatives and officials of companies active in the district who helped in many ways included: Mr. Jack W. Williamson of the Minerals and Chemicals Division of Englehard Minerals and Chemicals Corp., who took the author on several tours of strip mines and discussed many problems related to fuller's earth in the district; Messrs. Richard M. Jaffee, R. C. Valenta, and Wayne Bennett of the Oil-Dri Corp. of America, whose help included assistance in observing an exposure in a strip mine near Ochlocknee, Ga.; Mr. Robert P. Smith of the Waverly Mineral Products Co., Meigs, Ga.; Mr. A. J. Sapp of the Floridin Division of the Pennsylvania Glass Sand Corp., Quincy, Fla.; Mr. Doyle B. Crosten of the Pennsylvania Glass Sand Corp., Ochlocknee, Ga.; Mr. Marvin Verser of the Dresser Minerals Division of Dresser Industries, Havana, Fla.; Mr. W. H. Swanson, Milwhite Co., Attapulgus, Ga.; and Mr. Stanley T. Smith of Cherokee Industries, Ochlocknee, Ga. Company geologists who helped the author in the field include W. L. Otwell of the Floridin Division of Pennsylvania Glass Sand Corp. and A. J. Ross of Dresser Minerals Division of Dresser Industries. Fred Mencenberg, former geologist for the Dawes Silica Mining Co., Dawesville Siding, Ga., aided the author on several occasions in understanding the local geology.

## PREVIOUS WORK

The first published geologic discussions of the fuller's earth in the Meigs-Attapulgus-Quincy district were by Vaughn (1902, 1903), who outlined what was known of both the Florida and the Georgia parts of the district at that time. Additional information about the location of the deposits and production of fuller's earth in the Florida part of the district was given by Sellards (1908, 1910, 1914a, p. 28-35) and by Sellards and Gunter (1909). Sellards and Gunter's report is particularly valuable, because it includes a small-scale map locating exposures of fuller's earth in Gadsden County that no longer crop out. Apparently the exposures were in stream channels that are now buried by alluvium deposited by aggrading streams. Sellards and Gunter also made the only published estimate of the resources of fuller's earth in the Florida part of the district. Shearer (1917) described several exposures of fuller's earth in streambanks, roadcuts, and mines in the Georgia part of the district. Most mines and plants in the district are located on a map by Shrum (1970). Additional information was given by Bay and Munyan on deposits in Georgia (1935, 1940a, p. 278-289) and in Florida (1940b, p. 310-333).

The clay mineral attapulgite[1] was named (Lapparent, 1935, 1936) for clay occurring in the fuller's earth near Attapulgus, Ga., and the structure of attapulgite was worked out (Bradley, 1940) on clay from this district. Kerr (1937) visited and sampled deposits of fuller's earth near Attapulgus, Ga., and Quincy and Midway, Fla., and after a laboratory investigation of these and other clays concluded that the fuller's earth is probably a water-deposited weathering product. Two doctoral theses were concerned with attapulgite in this region. A thesis by Gremillion (1965b) dealt mainly with the origin of the palygorskite in the Meigs-Attapulgus-Quincy district, and one by McClellan (1964) reported on both the origin of this mineral and its distribution in most of northern Florida and southern Georgia. The restriction of the fuller's earth mined in Georgia to the Gulf trough (see section on "Gulf Trough") was noted by Owen (1963, p. 24) and Sever (1964). However, the occurrence of the fuller's earth in the vicinity of Quincy, Fla., within a sedminetary basin, had been known since 1893. Johnson (1892) had earlier recognized that an embayment of the Gulf of Mexico had once extended over most of this area.

Three major attempts have been made to map the rocks underlying the Coastal Plain of Georgia (Veatch and Stephenson, 1911; Cooke, 1943; MacNeil, 1947). The three maps produced by these geologists are quite different, and comparison of them shows clearly the difficulties in interpreting the poorly exposed rocks of the Coastal Plain.

## GEOMORPHOLOGY

The Meigs-Attapulgus-Quincy district is in the east-central part of the East Gulf Coastal Plain section of the Coastal Plain physiographic province. The region is underlain by very gently dipping sedimentary rocks, and formations crop out in broad belts. All surface runoff of the district reaches the Gulf of Mexico. The entire central part of the district is drained by the Ochlockonee River. The western part of the district in Georgia is drained by the Flint River. This river joins the Chattahoochee River at the southwest corner of Georgia; below this junction the river is called the Apalachicola. A few small tributaries flow into the Apalachicola River from the western part of the district in Florida. Some of the runoff reaches the Gulf of Mexico through the Aucilla River, which flows south from the eastern part of the district.

All of the district but the westernmost and southernmost parts is in a belt of dissected flat-topped uplands that in Georgia has been named the Tifton Upland (Cooke, 1925, p. 36-39) and in Florida the Tallahassee Hills (Cooke, 1939, p. 20-21; Puri and Vernon, 1964, fig. 5). Within the district, the surface of the Tifton Upland-Tallahassee Hills ranges from 120 to 320 feet above sea level. Incised valleys, some of which have broad flood plains, cut deeply into this upland plain, and in places the local relief in the rolling hills forming the valley walls is as much as 150 feet. In Florida, the Apalachicola Valley forms the western boundary of the Tallahassee Hills. In Georgia, the western boundary of the Tifton Upland is formed by a low cuesta commonly called the solution escarpment. This low west-facing escarpment extends northeast parallel to and a short distance east of the Flint River, and its local relief ranges from 100 to 150 feet. A low flatland called the Dougherty Plain, which is pockmarked by abundant sinkholes, extends westward from the foot of the solution escarpment. The altitude of the Dougherty Plain ranges from 80 to 130 feet above sea level west of the Meigs-Attapulgus-Quincy district. In the southernmost part of the district, the Tallahassee Hills surface terminates in a slope called the Cody Scarp (Puri and Vernon, 1964, fig. 5). This low scarp slopes in a southerly direction to the level of the Gulf Coast lowlands, which have an altitude of no more than 100 feet above sea level at most places.

### LINEAR TRENDS

Parallelism of drainage, rectangular patterns of some streams, alinement of karst features, and other linear trends observable on aerial photographs are widespread in northern Florida and southern Georgia. Linear trends, mainly parallelism in the drainage pattern in the Florida part of the Meigs-Attapulgus-Quincy district, have been described by Hendry and Yon (1958, p. 22-23). Rectangular stream patterns have also been recognized by Moore (1955, p. 15-16) in Jackson County, Fla., west of the district. East of the district, linear trends have been recognized in Leon County (Hendry and Sproul, 1966, p. 25, fig. 25) and Jefferson County, Fla. (Yon, 1966, p. 24, 25, fig. 9).

Theories to explain the origin of the linear trends have been presented, but as yet, none of the ideas has been supported by sufficient evidence to be considered more than a possibility. Tanner (1966, p. 85, 87, fig. 1), who called the trends "linears," believed some of them to be faults and named one of them the "Bainbridge-Chattahoochee-Blountstown fault." However, he presented no evidence for displacement along a fracture, and the idea that the linear trends in the Meigs-Attapulgus-Quincy district are faults can be considered as no more than one of several possible explanations of origin. Moore (1955, p. 15) expressed the opinion that the linear trends have been produced by jointing, an idea also favored by Yon (1966, p. 25). The author of this

[1]As recommended by the Clay Minerals Society Nomenclature Committee (Clays and Clay Minerals, 1971), attapulgite and palygorskite are considered synonymous; palygorskite has priority because it is the older name. However, attapulgite is retained in a few places in this report, particularly with reference to the older literature, to aid in documenting that this mineral was named after one of the oldest, and still active, fuller's earth-producing centers in the district.

report agrees with Moore and Yon that the trends are controlled by joints but believes that the alinements showing on aerial photographs result from solution of carbonate rocks along the joints by subsurface water. The reason some solution is thought to be necessary is that joints along which neither solution nor displacement has taken place would not show on aerial photographs. No sound evidence for faulting in the district has been presented, but there is ample evidence of widespread solution.

### SOLUTION FEATURES

Solution features are so abundant in southwestern Georgia and northern Florida that the region has been referred to as the lime-sink district (Fenneman, 1938, p. 52-53). However, the most abundant and most obvious evidence of solution occurs in the areas surrounding the Meigs-Attapulgus-Quincy district. Toulmin and Winters (1954) investigated the solution features in rocks older than those cropping out in the district, and Herrick and LeGrand (1964) recognized several phases of the karst cycle in the solution escarpment in the western part of the district and the old-age solution plain of the Flint River farther west. The large lake basins in the southeastern part of the district were known to have formed by the solution of carbonate rock before Sellards (1914b, p. 119-130) published his second report on them.

Widespread karst formation is absent in the central part of the district because this area is along the axis of the Gulf trough and is underlain by a thick section of the less soluble clastic sediments of the Hawthorn Formation and the Miccosukee Formation as used by Hendry and Yon (1967). Nevertheless, the upland surface of the entire central belt, particularly its northern and southern parts, has numerous shallow closed depressions, indicating deep-seated carbonate solution. These depressions range in length from a few feet to as much as half a mile, and most are no more than 30 feet deep. Some are filled with water, but others have internal drainage efficient enough for them to be used as pasture land. The conclusion that the closed upland depressions were formed by slump due to solution of underlying carbonate rocks is based on the following observations: (1) Solution features are abundant in the surrounding lime-sink district. (2) Well cuttings and cores from the carbonate rocks commonly contain abundant solution cavities and vugs. (3) Caverns are known to be common in carbonate rock at depth, as well drillers frequently report that their tools drop or that circulation is lost when they penetrate the upper part of the Suwannee Limestone. (4) The carbonate rocks of Oligocene age at depth in the region of the upland closed depressions commonly have been dolomitized, and some beds are nearly pure dolomite. Much of this dolomite is in macroscopic euhedral crystals, indicating postdepositional origin and intense chemical alteration, during which much of the original rock was dissolved. (5) In part of the district, contour maps of the upper surface of Oligocene rocks, based mainly on subsurface data (Hendry and Sproul, 1966, fig. 16), show a karst surface.

In addition to the sinkhole slumpage indicated by the upland closed depressions, completely filled sinks having no surface expression are known to exist. Such filled sinkholes were cut during highway excavation near Thomasville, Ga. (fig. 2), when U.S. Highway 19 was relocated. The land surface above these slumps shows no enclosed depression or other evidence of the slumps, which suggests that concealed sinkholes could be very common in the district.

FIGURE 2.—Slump caused by solution of lower rocks. Exposed in cut of U.S. Highway 19, 3 miles northeast of the center of Thomasville, Ga.

## GEOLOGIC STRUCTURE

### REGIONAL STRUCTURE OF THE COASTAL PLAIN

The Meigs-Attapulgus-Quincy district is within the extensive belt of gently dipping sedimentary rocks underlying the Coastal Plain. In most of the Coastal Plain of Georgia, these layered rocks strike northeast and dip toward the Atlantic Ocean. The strike shifts to a more westerly direction approximately along the Chattahoochee River, which forms the boundary between Georgia and Alabama west of the Meigs-Attapulgus-Quincy district. Along the river and farther west, the dip is to the south, toward the Gulf of Mexico. In most places the dip is so gentle that it cannot be observed in outcrops, and it can rarely be measured by field methods. One of the places where the dip can be measured is along the Chattahoochee River, where Toulmin and LaMoreaux (1963, p. 385) measured many sections and, using the river level as a datum, found that beds of early Tertiary age dip 13 feet per mile. Dips based on outcrops of the Tampa Limestone along the Apalachicola River farther south are only 7-10 feet per mile (Sellards and Gunter, 1918, p. 34).

### GULF TROUGH, A STRUCTURAL FEATURE (?)

An elongate belt in which sedimentary rocks of Miocene age are much thicker than on either side (fig. 3) extends northeast across the Meigs-Attapulgus-Quincy district. In Florida, this belt is in the northern part of a geologic feature that was recognized as an embayment of the Gulf of Mexico, which Johnson (1892) named the Chattahoochee embayment. This feature is now called the Apalachicola embayment (Pressler, 1947, p. 1853; Puri and Vernon, 1964, p. 1, fig. 2; Hendry and Sproul, 1966, p. 95). This same embayment has been called the Southwest Georgia basin by several authors, but "embayment" is preferred over "basin" because this feature is not closed on its southern end. Also, Apalachicola seems more appropriate than Southwest Georgia because much of the embayment is in Florida. Several authors have illustrated the Apalachicola embayment as large and triangular, having one side along the Gulf of Mexico in the vicinity of the delta of the Apalachicola River and the apex in southwestern Georgia. Actually, the elongate belt of thick Miocene rocks extends much farther northeast. All the elongate belt in Georgia, including the northern part of the Apalachicola embayment, was named the "Gulf Trough of Georgia" by Herrick and Vorhis (1963, p. 55, figs. 2, 3); Hendry and Sproul (1966, p. 97) dropped the Georgia restriction to the name and used simply the "Gulf trough." In this report, "Gulf trough" denotes the entire belt of thick Miocene rocks in the district, including the northern part of the Apalachicola embayment as located by several authors.

The origin of the Gulf trough is uncertain and, because of meager evidence, is the subject of much difference of opinion among geologists. Herrick and Vorhis (1963, p. 55) described the trough as a structural feature when they first proposed the name; however, they did not indicate whether they thought it was a graben, a syncline, or something else. Sever (1962), Gremillion (1965b, p. 47-48), Tanner (1966, p. 85, fig. 1), and Hendry and Sproul (1966, p. 96) favored the hypothesis that the trough is a graben. Owen (1963, p. 24) referred to it as a "syncline or downfaulted area." Sever (1964, fig. 2) illustrated it in cross section as a syncline, but in later reports (Sever, 1966a, p. C12, figs. 1-3; 1966b, p. 8, figs. 3-4) he showed it as a syncline with a fault on the southeast side.

The understanding of the origin of the Gulf trough was further complicated by the proposal of the so-called Ochlockonee fault and Barwick arch by Sever (1966a, p. C12, figs. 1-3; 1966b, p. 8, figs. 2-4) and of the Bainbridge-Chattahoochee-Blountstown fault by Tanner (1966, p. 85, 87, fig. 1). If they exist, the Ochlockonee fault and the Barwick arch would form the southeast side of the trough, and the Bainbridge-Chattahoochee-Blountstown fault would form the northwest side of the trough; and the trough would be a graben. Because the origin of the Gulf trough relates to the fuller's-earth deposits and ground-water resources of southwestern Georgia, the author, with the cooperation of S. M. Herrick of the U.S. Geological Survey, Atlanta, Ga., restudied the pertinent geologic data. The following paragraphs outline the conclusions reached. These conclusions were outlined in somewhat greater detail in a report by Patterson and Herrick (1971).

The structural features proposed by Sever were based on data obtained from many water-well samples and logs and from a very few outcrops. The most reliable key horizon in these data is the top of the Suwannee

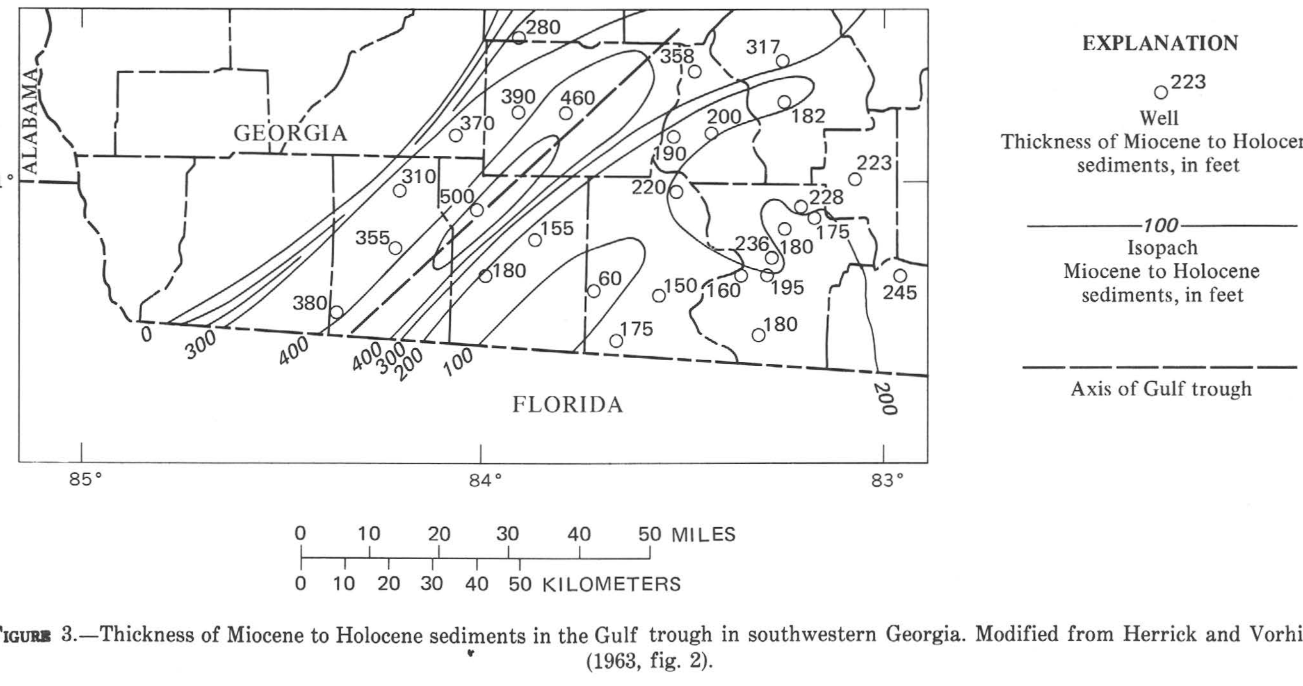



FIGURE 3.—Thickness of Miocene to Holocene sediments in the Gulf trough in southwestern Georgia. Modified from Herrick and Vorhis (1963, fig. 2).

Limestone; younger rocks are characterized by discontinuous beds and by vertical and lateral gradations. Most of the altitudes on which Sever (1966a, fig. 1; 1966b, fig. 2) based his contour map of the top of the Suwannee Limestone are fairly accurate. The top of this formation is definitely higher in the area of his Barwick arch than in the central part of the Gulf trough. However, no evidence exists in any of these data to indicate movement along a fracture; therefore, the Ochlockonee fault is nothing more than a hypothetical possibility.

Considerable doubt also exists whether the broad low feature in the Suwannee Limestone, the so-called Barwick arch, is actually an anticline or was formed by something other than tectonic forces. The apparent dip to the southeast on the east side of the high corresponds to the regional dip, and the inclination of the top of the Suwannee Limestone to the west, into the Gulf trough, is little more than 20 feet per mile. The apparent high may be nothing more than a carbonate-rock area which has undergone less ground-water solution than the area on the northwest side of the high. Contour maps of the top of the Suwannee Limestone (Hendry and Sproul, 1966, fig. 16; Yon, 1966, fig. 10) in Leon and Jefferson Counties, Fa., to the south show a karst topography, and the highs are similar to the so-called Barwick arch. This hypothetical arch could also represent an Oligocene shoal area separated from the mainland by deeper water, and the gentle apparent inclination of beds on its northwest side could be initial dip. The high of the so-called Barwick arch probably represents carbonate deposition in a shoal area that was later modified appreciably by ground-water solution. In any event, the existence of an arch formed by crustal doming has not been supported by sound geologic observations, and until evidence for the existence of such an arch is presented, the formal name "Barwick arch" should be considered invalid.

The existence of the Bainbridge-Chattahoochee-Blountstown fault of Tanner (1966, p. 85, 87, fig. 1) is also questionable and should not be considered as support for the graben hypothesis for the origin of the Gulf trough. Tanner did not present the evidence for this fault in the article in which he proposed it; he only indicated that it is along the west side of the Gulf trough, which he called the Southwest Georgia graben, and that its position is suggested by a "linear." As previously noted, linear trends occur in several directions in the Meigs-Attapulgus-Quincy district, but as yet none have been proved to be faults. Therefore, the Bainbridge-Chattahoochee-Blountstown fault, like the Ochlockonee fault of Sever, is no more than a hypothetical possibility.

The idea that the Gulf trough is a graben has not been convincingly supported; there is also little to support the other possibilities for the origin of this feature. The Gulf trough is only known to be an elongate belt in which Oligocene and Miocene rocks are thicker than on either side. The trough in which these sediments accumulated could have been an erosional valley or a strait instead of a graben or syncline. Modification of the trough by post-Oligocene solution of carbonate rock by ground water undoubtedly took place, but it seems unlikely that the entire trough is a solution valley.

In the author's opinion, the Gulf trough was most likely a strait separating peninsular Florida from the mainland during Oligocene and much of Miocene time. The principal reason for this opinion is that isophachous maps of Miocene and Oligocene (Herrick and Vorhis, 1963, figs. 2 and 3) and Miocene (Toulmin, 1952, fig. 7) rocks in the trough show an outline similar to that of the present Straits of Florida (Uchupi, 1966), which separate Florida from the Great Bahama Banks. The idea that peninsular Florida was separate from the mainland in the past is not new, as Dall (Dall and Harris, 1892, p. 111, 121-122) proposed the "Suwannee Strait" for a belt of thick Miocene sediments much farther east than the Gulf trough. Rainwater (1956, p. 1727) suggested that the Suwannee Strait extended along the Georgia-Florida boundary as far west as Jackson County, Fla., which is west of the Meigs-Attapulgus-Quincy district. He, therefore, deserves credit for the idea of a strait in this region, but his alinement of the strait is east of the Gulf trough's outline on isopachous maps.

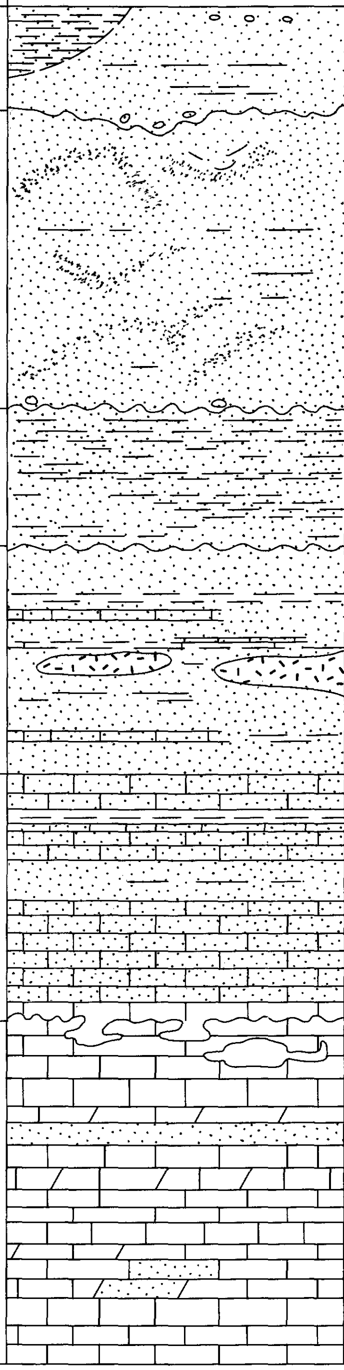
## STRATIGRAPHY

Nearly all the rocks exposed in the Meigs-Attapulgus-Quincy district are of Miocene age or younger (fig. 4). However, limestone of Oligocene age is below only a shallow blanket of residuum at places on the Dougherty Plain along the western margin of the district, and limestone float containing Oligocene Foraminifera was found in the eastern part of the district. Little mention will be made of rocks older than Oligocene, because they have been penetrated by only a few deep wells within the district. These deeper rocks are not known to contain valuable resources other than ground water; however, implication that oil, gas, or valuable minerals will never be found in them is not intended.

### OLIGOCENE SERIES

#### SUWANNEE LIMESTONE

*Name.*—The name Suwannee Limestone was proposed by Cooke and Mansfield (1936) for yellowish limestone exposed along the Suwannee River from Ellaville nearly to White Springs, Fla. It has since been used by several authors writing about the geology of northern Florida, including Hendry and Sproul (1966, p. 58-60) in the southern part of the district described in this report and Moore (1955, p. 51-58) in the area farther west. Cooke (1943, p. 84-86) used the name Suwannee



| SERIES | FORMATION | THICKNESS (FEET) | DESCRIPTION |
|---|---|---|---|
| Holocene and Pleistocene | | 0–60 | Alluvial and eolian deposits of sand, silt, and muck |
| Miocene | Miccosukee Formation as used by Hendry and Yon (1967) | 0–80 | Reddish-brown, brown, and yellowish-brown clay, medium to coarse sand, and thin kaolinitic clay beds; crossbedded; contains channel-fill deposits and lenticular units of quartz gravel; marine fossils absent but contains *Callianassa* borings locally |
| Miocene | Jackson Bluff Formation as used by Hendry and Sproul (1966) | 0–20 | Greenish-gray and brown sandy clays and clayey sands; contains abundant marine fossils |
| Miocene | Hawthorn Formation | 100–275 | Fine to medium quartz-sand and clayey silt; contains fuller's earth and other clays and scattered very sandy limestone beds; locally contains minor pelletal and secondary phosphate, opal concretions, and irregular masses of opal |
| Miocene | Tampa Limestone | 25–250 | Light-gray and light-grayish-brown very sandy limestone, quartz sand, and thin clay beds; locally contains minor dolomitic sandy limestone and, in places, massive white limestone occurs in lower part; Foraminifera rare |
| Oligocene | Suwannee Limestone | 24–230 | Light-yellow to light-brown crystalline limestone containing much dolomitic limestone and scattered beds of dolomite; white crystalline limestone occurs in upper part locally; minor quantities of white quartz sand is present in some beds, and opal and chert masses are common; Foraminifera locally abundant |

FIGURE 4.—Generalized stratigraphic section of the rocks exposed in the Meigs-Attapulgus-Quincy district.

Limestone in southern Georgia and thought that this formation is the littoral equivalent of the Flint River Formation, a name he used for Oligocene beds in the Dougherty Plain region. Several authors (MacNeil, 1947; Owen, 1963, p. 19; Sever and Herrick, 1967; Sever, 1966a) have also used this formational term in the southwestern part of Georgia.

*Distribution.*—Because outcrops of the Suwannee Limestone are rare in the Meigs-Attapulgus-Quincy district, most of what is known about this formation has come from studies of water-well cuttings and drill cores. Even the subsurface information on this formation is incomplete because few wells penetrate far into it. This limestone is one of the best aquifers in the region, and most wells obtain adequate supplies of water from its upper part.

The Suwannee Limestone is below only a thin blanket of residuum at places on the Dougherty Plain in the westernmost part of the district. In this area, the top of the formation is 80 to 120 feet above sea level. The top of the formation dips eastward below younger formations from the solution escarpment on the east side of the Dougherty Plain into the axial part of the Gulf trough. It is 212 feet below sea level at well GGS-495, 3 miles southeast of Meigs, Ga., in the northern part of the district; 266 feet below sea level at Cairo, Ga.; and 225 feet below sea level in a well at Attapulgus, Ga. East of the Gulf trough, the top of the formation is at altitudes ranging from 120 to 175 feet above sea level. Limestone float containing Oligocene Foraminifera was found at one locality on the east side of the trough, but no outcrops of Suwannee Limestone were found in place in Georgia.

*Lithology.*—In the Meigs-Attapulgus-Quincy district, the Suwannee Limestone observed in well cuttings consists chiefly of light-yellow or cream-colored dolomitic limestone. A few beds contain fine-grained quartz sand, and the upper part of the formation in a few places contains virtually pure white crystalline limestone. Cuttings of some beds, particularly in the deep, central part of the Gulf trough, are nearly pure light-brown dolomite. Cuttings of the upper part of the formation from both the Georgia and the Florida parts of the district contain much white and light-brown opal. The abundance of secondary silica in the form of opal and chert in the upper part of the formation is apparently widespread, as it has been noted in many places in Florida (Hendry and Sproul, 1966, p. 58, 59; Cathcart, 1963b, p. D11-D12).

*Thickness.*—The Suwannee Limestone is only 24 feet thick where penetrated by a well at Cairo, Ga. (Sever and Herrick, 1967, p. B50), but scattered wells in this region have passed through 50 to 90 feet of this formation without reaching its base. Cole (1944, p. 13) found the Suwannee Limestone to be 230 feet thick at Quincy, Fla., and Hendry and Sproul (1966, p. 59) indicated that it is as much as 204 feet thick in Leon County, Fla. Originally, the Suwannee Limestone probably extended more uniformly over the entire district than the foregoing figures indicate, but much of the formation has been removed by solution. The following facts provide evidence for solution: (1) Many sinkholes are found in the Dougherty Plain on the west edge of the district, where the Suwannee Limestone is under only a thin blanket of residuum; (2) drillers commonly report that their tools drop when the Suwannee Limestone is reached, indicating that a cavern has been penetrated; (3) so-called structure maps of the top of the Suwannee Limestone in Leon County, Fla. (Hendry and Sproul, 1966, fig. 16), and in the next county to the east (Yon, 1966, fig. 10) reveal a subsurface karst topography.

*Stratigraphic relations.*—The Suwannee Limestone is overlain by the Tampa Limestone. The Suwannee contains much less sand and is ordinarily either much whiter and more crystalline or more dolomitic than the younger, Tampa Limestone. Much of the Suwannee Limestone also contains abundant Oligocene microfossils. Some of the common Foraminifera genera are *Rotalia, Lepidocyclina, Operculinoides,* and *Quinqueloculina.* The Suwannee Limestone has much higher porosity and permeability than the Tampa Limestone, as indicated by abundant vugs and larger cavities, most of which are lined with carbonate crystals.

Hendry and Sproul (1966, p. 59) noted that the Suwannee overlies upper Eocene beds unconformably in Leon County, Fla. Cooke (1943, p. 85) concluded that it rests unconformably on an older formation in southern Georgia.

## MIOCENE SERIES

### TAMPA LIMESTONE

*Name.*—The name Tampa Limestone is used in this report for all beds between the Suwannee Limestone of Oligocene age and the Hawthorn Formation. This usage follows that of Cooke (1943, p. 86-89) in Georgia and Cooke and Mossom (1929, p. 78-96) in Florida. In more recent stratigraphic work in Florida (Puri, 1953, p. 17-21), the name Tampa is used as a stage, and two lithofacies, the calcareous St. Marks facies downdip and the sandy and silty Chattahoochee facies updip, are recognized. Both facies are present in the Meigs-Attapulgus-Quincy district; however, they are virtually impossible to distinguish in some areas because one grades laterally into the other. For this reason the older term, Tampa Limestone, rather than the facies names, is used in this report.

*Distribution.*—The Tampa Limestone underlies the entire district, except for a very narrow belt along the western side of the district and a few small areas. It has been removed by solution in some sinkholes and is absent in the vicinities of Lakes Iamonia and Miccosukee, where, according to Hendry and Sproul (1966, p. 63), it was removed by erosion and solution. However, the Tampa Limestone may never have been deposited in these areas, particularly if the area east of the Gulf trough was a shoal during Miocene time.

The Tampa Limestone is well below the surface in most of the district, and exposures are rare. The best exposures are on the east side of the Chattahoochee-Apalachicola River in the vicinity of Chattahoochee, Fla., and in scattered sinkholes along the solution escarpment in Georgia.

*Stratigraphic relations.*—As noted by Cooke (1943, p. 87), "The stratigraphic relations of the Tampa Limestone are somewhat conjectural because of the scarcity and obscurity of critical exposures." The differences in lithology and the irregular thickness of both formations suggest that the Tampa Limestone overlies the Suwannee Limestone unconformably. However, the lithologic differences between the formations are not so clear in some of the deep, central parts of the Gulf trough, where both formations have been dolomitized. Foraminifera are ordinarily not abundant in the Tampa Limestone, but *Archaias* and *Sorites* occur in a few beds. The contact between the Tampa Limestone and the overlying Hawthorn Formation is gradational and will be discussed in more detail.

*Lithology.*—The Tampa Limestone is mainly a dull chalky very sandy bedded limestone. Locally, it contains clay and sandy beds, and some beds are dolomitic. Dolomite beds are exposed in a borrow pit northeast of the bridge over the Apalachicola River at Chattahoochee, Fla. (table 1, sample 12) and dolomitic limestone, clay, and sand layers were noted in several wells in the central part of the Gulf trough.

*Thickness.*—The Tampa Limestone varies considerably in thickness. It is thickest in the central part of the Gulf trough where some wells have penetrated more than 250 feet of rock having the lithologic characteristics of this formation. It is rarely more than 125 feet thick on either side of the trough, and in places it is less than 25 feet thick.

### HAWTHORN FORMATION

*Name.*—The term "Hawthorne beds" was originally applied to beds of phosphatic sandstone, sands, ferruginous gravels, and greenish clays exposed in Alachua County, Fla., by Dall (Dall and Harris, 1892, p. 107). The name Hawthorn Formation has since been used throughout northern Florida and most of the Coastal Plain region of Georgia and Alabama for problematical beds in several different ways. Most of the problems related to this formation result from its variable characteristics, its gradational relationship with the formations above and below it, and poor and weathered exposures, which make it impossible to observe all of the formation at one place. Because of these characteristics, the "Hawthorn Formation," as noted by Puri and Vernon (1964, p. 145) "perhaps is the most misunderstood formational unit in southeastern United States. It has been the dumping ground for alluvial, terrestrial, marine, deltaic, and prodeltaic beds of diverse lithologic units in Florida and Georgia, that are stratigraphic equivalents of the Alum Bluff Stage."

In one of the early attempts to map the Coastal Plain rocks of Georgia, Veatch and Stephenson (1911) used the term Alum Bluff Formation for most of the rocks that several more recent authors have considered to form the Hawthorn Formation. Cooke (1943, p. 89-98, pl. 1) included all the rocks younger than the Tampa Limestone in the Georgia part of the Meigs-Attapulgus-Quincy district in the Hawthorn Formation. This usage would include beds assigned to younger units in this report as part of the Hawthorn Formation. MacNeil (1947) combined the Hawthorn Formation and the Duplin Marl into a single map unit and showed the general area that the Hawthorn Formation is thought to occupy in this report as the Chipola Formation and Tampa Limestone, undifferentiated. Several older reports on Florida geology treat the Hawthorn Formation in the part of the Meigs-Attapulgus-Quincy district in that State as including all clastic rocks younger than the Tampa Limestone. This usage is virtually the same as Cooke's (1943) treatment of the formation in Georgia. In the most recent thorough work by the Florida Bureau of Geology in the vicinity, Hendry and Sproul (1966, p. 65-74, pl. 1), however, restricted the Hawthorn Formation to predominantly marine beds between their St. Marks Formation (Tampa Limestone of this report) and their Jackson Bluff and Miccosukee Formations.

In this report, the name Hawthorn Formation is applied to rocks that are primarily of marine origin that overlie the Tampa Limestone. The rocks above the Hawthorn Formation throughout most of the Meigs-Attapulgus-Quincy district are assigned to the Miccosukee Formation as used by Hendry and Yon (1967), but in the southernmost part of the district, the thin Jackson Bluff Formation as used by Hendry and Sproul (1966, p. 75) is present between the Hawthorn and Miccosukee Formations.

*Age.*—The age of the Hawthorn Formation has been somewhat of a problem for some time, partly because of the differing interpretations of beds included in it. Early investigators considered the fuller's earth in this formation to be of Oligocene age (Vaughn, 1902, p. 923), and Veatch and Stephenson (1911, p. 342-362) treated most of the rocks assigned to the Hawthorn Formation in this report as the Alum Bluff Formation, which at that time was thought to be of Oligocene age. Cooke (1943, p. 89-98, pl. 1) assigned a Miocene age to the Hawthorn Formation, but he included in the formation beds which Veatch and Stephenson thought were as young as Pliocene. Some of these younger beds included in the Hawthorn Formation by Cooke are assigned to the overlying Miccosukee Formation (Hendry and Yon, 1967) in this report.

In recent years, general agreement has been reached that the Hawthorn Formation is of Miocene age; however, confusion still exists whether the formation is of early or middle Miocene age. The best evidence for Miocene age has come from several types of fossils collected from fuller's-earth pits. Vertebrate fossils considered to be of Miocene age have been collected from the overburden above the fuller's earth in pits at Quincy and Midway, Fla. (Cooke, 1943, p. 91). Diatoms, which are abundant in the fuller's earth in the vicinity of Meigs and Ochlocknee, Ga., have been correlated with those occurring in the Calvert Formation of Maryland (Gremillion, 1965b, p. 46), which is of middle Miocene age. Diverse suites of fossils have been collected from an interval of 10 to 19 feet above the fuller's earth at the Milwhite pit southwest of Attapulgus, Ga. The mollusks from these beds were studied by Druid Wilson, the Foraminifera, by S. M. Herrick, and the ostracodes, by J. E. Hazel. All three paleontologists concluded that the fossils in this suite are of Chipola age, which, according to Keroher and others (1966, p. 779), is early Miocene. Puri and Vernon (1964, p. 126, fig. 14) considered the Chipola Formation to be in facies relationship with the Hawthorn Formation and both parts of the Alum Bluff Group of early and middle Miocene age. Probably the best solution for an age assignment for the Hawthorn Formation is to recognize that it is neither the youngest nor the oldest of the Miocene formations in the Coastal Plain and that the middle Miocene is a realistic age assignment for this formation.

*Distribution.*—The Hawthorn Formation extends throughout the Meigs-Attapulgus-Quincy district, except for a belt along the western boundary of the district and scattered solution depressions in the eastern part, where it has been eroded. The formation is blanketed by younger formations in all upland areas. Virtually all major stream valleys in the central part of the district cut into but not through the Hawthorn Formation. However, most valley walls formed by this formation are covered by slope wash, slumped material, and vegetation, and natural exposures are rare.

*Lithology.*—All the valuable fuller's-earth deposits in the Meigs-Attapulgus-Quincy district are in the Hawthorn Formation, but this formation consists chiefly of fine- to medium-grained quartz sand, containing much silt and clay, minor carbonate beds, and traces of phosphatic material. The fuller's earth is in irregular lenticular units and discontinuous beds which are described in more detail in the section on economic geology. The sand is mostly rounded and subrounded quartz, and most of it is intermixed with clay and silt. Most clay other than that in the fuller's-earth deposits consists of mixtures of palygorskite and montmorillonite, but much of the clay in weathered parts of the formation is kaolinitic, and kaolinite is virtually the only clay mineral present in thoroughly weathered parts. The carbonate beds consist chiefly of very sandy limestone; some are dolomitic. Most of the carbonate beds are no more than 5 feet thick and are interbedded with sand, some of which is sufficiently cemented with calcite to be called sandstone. Carbonate beds are much more abundant in the central part of the Gulf trough, where the Hawthorn Formation is much thicker than on either side. Carbonate beds occur above the fuller's earth in the area south of Attapulgus, Ga., but none are present above the clay in the northern part of the district. Studies of drill cores and water-well samples reveal that carbonate beds are abundant at depth in the central part of the Gulf trough, and at places so much sandy limestone is present that the Hawthorn Formation grades downward into the Tampa Limestone, which is also sandy. Most of the phosphate in the Hawthorn Formation is in scattered pelletal grains and fish teeth and bones consisting of carbonate-fluorapatite. Most of the phosphate pellets at depth are black and shiny, and those in the shallower, more weathered parts are brown, tan, or light gray.

Opal occurs in the Hawthorn Formation at several localities. Masses as much as 3 feet thick of light-yellowish-gray brecciated flintlike brittle opal, which weathers white, occur 1.7 miles south of Cairo, Ga. This opal, which is distinguished from chert by X-ray methods, is chiefly hydrous silica (table 1, samples 9 and 10), but it also contains minor quantities of palygorskite and possibly other clay minerals as well as some detrital quartz. Clayey opal concretions are common in parts of the fuller's earth in the northern part of the district (p. 22). Opal either in the Hawthorn Formation or in the underlying Tampa Limestone has been noted at other localities in south Georgia (Spencer, 1891, p. 82; Brantly, 1916, p. 199; Veatch and Stephenson, 1911, p. 344, 352).

Fossils are rare in most of the Hawthorn Formation. However, some of the carbonate beds exposed in fuller's-earth mines in the southern part of the district are almost coquina, and these beds also contain Foraminifera and ostracode faunas. Microfossils are common in fuller's earth in the northern part of the district (p. 23). Both vertebrate fossils and petrified tree trunks have been recovered from that part of the formation removed in stripping fuller's earth near Quincy and Midway, Fla.

*Stratigraphic relations.*—North of the Meigs-Attapulgus-Quincy district, the Hawthorn Formation apparently overlies several older formations unconformably (Cooke, 1943,p. 91). This formation also rests unconformably on the Tampa Limestone in the eastern part of Leon County, Fla., as indicated by differences in lithology between the two formations (Hendry and Sproul, 1966, p. 67). In the Gulf trough in the central part of the district, however, the Hawthorn Formation, as observed in well cuttings, grades gradually downward into the Tampa Limestone through a thick zone in which unfossiliferous sandy limestone layers increase in abundance downward. Where the gradation is present, only an arbitrary interpretation of the position of the contact between the two formations is possible, and there is no justification for assuming that an unconformity is present.

The contact of the Hawthorn with the overlying Miccosukee Formation (Hendry and Yon, 1967) is also problematical in many places. The principal criterion used in picking this contact is the upper limit of beds having definite marine characteristics. At places, the recognition of the top of marine beds was based on marine fossils and, at others, on the presence of limestone, pelletal phosphate, or palygorskite fuller's earth. This basis for picking the top of the Hawthorn Formation is similar to that used by Espenshade and Spencer (1963, p. 26) and Vernon (1951, p. 186-187).

Additional characteristics used in separating the two formations were the appreciably larger size of the sand grains and the more abundant white kaolin layers in the Miccosukee Formation. Also, an unconformity marked by coarse sand, gravel, and cobbles in channel-fill deposits in the lower part of the Miccosukee Formation occurs at several localities. In the highwall of an old strip mine south of Amsterdam, Ga., the basal zone of the Miccosukee contains cobbles of kaolin as much as 2 inches long in sand; in one of the Florida Bureau of Geology cores (table 5, well W7539), the cobbles in this stratigraphic position are francolite; and in the highwall of the active mine south of Attapulgus (pl. 1, mine E; table 3, sec. 5, bed 9), the top of the Hawthorn is marked by a weathered kaolinitic zone.

Though the criteria outlined for distinguishing the Hawthorn and Miccosukee Formations seem reliable, the two formations are extremely difficult to distinguish where weathering has progressed to considerable depths. The grain size within each of the two formations varies considerably, and in places none of the other characteristics for identifying the formations are present. Locally, some of the thin limestones have been removed by leaching, and the secondary phosphate minerals found at several localities suggest that all the pelletal phosphate may have been leached from some beds.

*Thickness.*—Over most of the district, the Hawthorn Formation is no more than 100 feet thick, but in the central part of the Gulf trough, some wells have penetrated beds more than 275 feet thick which could be considered part of this formation. However, wherever this formation is exceptionally thick, its lower part contains much sandy limestone. How much of this sandy limestone should be assigned to the Hawthorn Formation and how much to the Tampa Limestone is largely a matter of opinion.

### JACKSON BLUFF FORMATION AS USED BY HENDRY AND SPROUL (1966)

A thin formation called the Jackson Bluff Formation was mapped by Hendry and Sproul (1966, pl. 1) in the vicinity of Lake Talquin in the southern part of the Meigs-Attapulgus-Quincy district. This formation consists mainly of greenish-gray and brown sandy clays and clayey sands containing very abundant marine mollusk shells. It ranges in thickness from 0 to 20 feet. Its thickest part is along the southern boundary of the district, and it wedges out a few miles to the north.

The Jackson Bluff Formation has little bearing on the fuller's earth and other mineral resources discussed in this report, and the formation is noted here mainly to complete the stratigraphic sequence. However, it does have some bearing on the geology of the area, because its occurrence as a wedge between the Hawthorn Formation and Miccosukee Formation (Hendry and Yon, 1967) provides further evidence that the contact between these two formations is unconformable.

### MICCOSUKEE FORMATION AS USED BY HENDRY AND YON (1967)

Throughout most of the district, the Hawthorn Formation is overlain by a problematical clastic formation, which has been called the Miccosukee Formation (Hendry and Yon, 1967) in recent years. In Georgia, it was called the Atlantic Formation as early as 1892, and Veatch and Stephenson (1911, p. 400-423) called it the Altamaha (Lafayette?) Formation and considered it to be of Pliocene age. Other names and ages that have been assigned to it, according to Hendry and Sproul (1966, p. 78-82), who summarized much of the literature on this formation and cited appropriate references, include the Alum Bluff Formation (Oligocene to lower Miocene), the Hawthorn Formation (middle Miocene), unnamed coarse clastics and the Miocene red beds (middle-upper Miocene), and the Citronelle Formation (Pliocene-Pleistocene).

One of the major problems related to the Miccosukee Formation is its age, and much of the uncertainty is due to the scarcity of fossils. No fossils were found in this formation in the Meigs-Attapulgus-Quincy district; the only ones it is known to contain in the region are animal teeth of late Miocene age discovered (Yon, 1965) approximately 18 miles east of the district. These fossils and the position of this formation above the Hawthorn Formation (Miocene) make it reasonably certain that the Miccosukee is younger than middle Miocene. The upper part of the formation, however, may contain some beds of Pliocene age, and, if not, the only possible sedimentary record of the Pliocene Epoch preserved in the district is in the sand deposits considered to be of Pleistocene age in this report or in one of the lower soil horizons.

A second problem is the identification of both the upper and the lower contacts of the Miccosukee Formation and even of the entire formation at many places where it is thin and thoroughly weathered. The Miccosukee Formation overlies the Hawthorn Formation unconformably, as it overlaps the older Tampa Limestone (St. Marks Formation of Yon, 1966, p. 55) in Jefferson County and the younger Jackson Bluff Formation (Hendry and Sproul, 1966, p. 84) in Leon County, Fla. However, the unconformity is difficult to recognize in much of the Meigs-Attapulgus-Quincy district except in those localities noted on page 12, because the lithology of the upper part of the Hawthorn Formation is very similar to the lithology of the Miccosukee Formation. Pelletal phosphate, carbonate rock, and marine fossils in the Hawthorn Formation and their absence in the Miccosukee Formation are the main features used to distinguish between the two formations. The upper part of the formation is weathered, and it is difficult to determine whether or not younger sediments occur between it and the overlying soil. In some upland areas, a light-gray fine and medium-grained sand layer 3 to 6 feet thick occurs between the Miccosukee Formation and the A soil horizon. This sand layer probably contains eolian material of Pliocene-Pleistocene age.

The maximum thickness of the Miccosukee Formation in the Meigs-Attapulgus-Quincy district is approximately 80 feet. However, the formation is much thinner than this at most places, and it has been eroded completely in the areas occupied by the larger stream valleys. The maximum thickness measured was in Florida, where the formation is generally much thicker than in the northern part of the district. In the vicinity of the fuller's-earth pits near Meigs and Ochlocknee (pl. 1), it is only 15 to 25 feet thick.

Hendry and Yon (1967, p. 252) described the Miccosukee Formation in Jefferson and Leon Counties, Fla., as consisting of continental deposits, presumably because of the vertebrate fossils, lithologic character, and abundant crossbedding. However, burrows of *Callianassa*, which indicate littoral and shallow neritic environments (Weimer and Hoyt, 1964), were found in the upper part of the formation at one locality in the Meigs-Attapulgus-Quincy district (table 3, sec. 5, beds 4 and 6), indicating that at least part of the formation in this area was deposited under nearshore marine conditions. The burrows of *Callianassa* are similar to those referred to as *Halymenites* in the older geologic reports and as *Ophiomorpha nodosa* var. *spatha* in a recent paper by Hester and Pryor (1972).

The Miccosukee Formation consists mainly of lenticular reddish-brown, brown, and yellowish-brown clayey sands, clay beds, and local channel-fill deposits of gravel. The upper part is chiefly cut-and-fill deposits and is, in general, coarser grained than the lower part. Crossbedding is common throughout the formation. The clay beds range from paper-thin laminae to beds more than 5 feet thick. The fresh, deeply buried clay is greenish gray and is chiefly montmorillonite. The clay in the upper, thoroughly weathered part is ordinarily white and is chiefly kaolinite. Some of the kaolinite associated with gravel and coarse sand occurs as water-rounded clay balls. Weathered chalk-white chert is abundant in the upper part of the formation. The secondary phosphate mineral wavellite was found in the lower part of the formation at four localities, and francolite was found in core from one drill hole. The wavellite occurs as solid discoid and open boxworklike concretions. The francolite was in white water-rounded cobbles and appeared similar to kaolin.

#### UNCONSOLIDATED DEPOSITS OF PLEISTOCENE AND HOLOCENE AGE

Alluvial and eolian deposits consisting mainly of sand, silt, and muck are scattered throughout the Meigs-Attapulgus-Quincy district. Among the most extensive deposits are those thought to be associated with former shorelines, indicating higher stands of the sea during the Pleistocene Epoch. One belt of such deposits consisting mainly of sand, part of which is in dunes, extends along the south side of Lake Talquin, Leon County, Fla. This sand is as much as 80 feet thick and is considered by Hendry and Sproul (1966, p. 92-93) to form the Okefenokee Formation and to be a beach-dune sand. Extensive deposits of sand are at altitudes of about 100 feet above sea level along the Flint River in the vicinity of Bainbridge, Ga., and in terraces along the Ochlockonee River at altitudes of 180 to 200 feet above sea level. Deposits near Dawesville, Ga., which are dug for silica sand, are approximately 20 feet thick near the river and thin to a knife edge within approximately 1 mile northwest of the river. Similar terrace deposits occur east and southeast of Pine Park, Ga. A belt of impure sand deposits, probably eolian, occurs on uplands between Faceville, Ga., and Chattahoochee, Fla. (Veatch and Stephenson, 1911, p. 45-46). Most of these deposits are at altitudes of 275 to 300 feet above sea level. Sand, silt, and much of Holocene age underlie the broad, heavily vegetated flood plains of the rivers, which are as much as one-half mile wide. Silt and muck occur in swampy sinkhole depressions scattered throughout the district.

## ECONOMIC GEOLOGY

### FULLER'S EARTH

#### DEFINITION

As noted by Grim (1962, p. 321), the term "fuller's earth" comes from the use of fine-grained earthy materials and water in cleaning or fulling wool to remove the oil and dirt from it. The process is an ancient one and is referred to in the Bible (Mark 9: 3). The Romans used fuller's earth mined on the Italian mainland and shipped from Sardinia. The term has no compositional or mineralogical significance, and several types of clay and other fine-grained materials have been used in fulling. The usage of the term was modified in the latter part of the last century to include earths of value, without chemical treatment, in decolorizing and purifying mineral, vegetable, and animal oils. Such clay has been referred to as naturally active (Nutting, 1943) to distinguish it from activated clay, which requires acid treatment to be of value in purifying oil. Nutting included both naturally active and activated clays under the term "adsorbent clays." Adsorbent clays in this sense is similar to bleaching clay, but the latter, as used in the oil industries, also includes activated bauxite (Rich, 1960, p. 93).

Though the fuller's earth of the Meigs-Attapulgus-Quincy district was first used in purifying oils, the tonnage now produced for this purpose is surpassed many times by that sold for other uses. Nevertheless, the term "fuller's earth" is retained for these clays because of the lack of a more suitable term, and the production of this and similar clay is reported by the U.S. Bureau of Mines as fuller's earth. Perhaps some justification for the application of this term to so many products lies in the fact that the adsorbent property of the clay, or the product made from it, is the primary asset in most uses for which the clay is now sold.

## HISTORY AND USES

Published reports give a rather confusing account of the discovery of fuller's earth in the United States. Several reports state that fuller's earth was discoveed in this country in 1893 near Quincy, Fla., by the Owl Commercial Co. (predecessor of the present makers of White Owl cigars) during an attempt to burn brick from clays on tobacco property. The fuller's earth was unsuitable for making brick, but an Alsatian immigrant employed as a farm worker recognized that it was similar to clays used in Germany for fulling, and his observation led to the first mine near Quincy 2 years later. This was not the first discovery, however, because fuller's earth had been mined on a small scale in Arkansas in 1891 (Miser, 1913, p. 208) and tested for use in the refining of conttonseed oil. Both these reported discoveries are related to the use of fuller's earth in processing oils and fail to note its earlier uses. Clays and other earthy materials were undoubtedly used by the early settlers from Europe in cleansing wool and other materials. The author made little effort to search the historical records and document this but did find that soldiers stationed near Perth Amboy, N.J., used Woodbridge fire clay for cleansing buckskins during the Revolutionary War (Cooke and Smock, 1878, p. 1), and that fuller's earth associated with an iron-ore bed near Kent, Conn., had been mined prior to 1820 (Silliman, 1820, p. 217). Also, American Indians are reported to have used bentonite in cleaning blankets, and they probably dug it for other cleansing purposes prior to the Columbian period.

The use of fuller's earth in the refining of oils continued to be the major one for many years. The demand for fuller's earth for processing mineral oil increased rapidly in the first part of this century and reached a peak of approximately 317,000 tons in 1930 (fig. 5); this tonnage was 97.1 percent of the total United States production that year. The production of fuller's earth for this purpose decreased thereafter, dropping significantly when bauxite was introduced as a more efficient substitute in 1937, and magnesium silicate, in 1940. In recent years, the production of fuller's earth for use in refining mineral oils has maintained a rather uniform rate of 35,000 to 40,000 tons per year. The use of fuller's earth in processing animal and vegetable oils has never been a major one and has decreased to the point that it is included as a part of the miscellaneous uses in U.S. Bureau of Mines Yearbooks.

Fuller's earth was first sold for drilling mud in 1941. The market for this use expanded slowly and has maintained a level of 8 to 10 percent of the total United States production during the last few years. Most of the fuller's earth sold for drilling mud comes from the southern part of the Meigs-Attapulgus-Quincy district. For several years, attapulgite clay mined in the soutern part of the Meigs-Attapulgus-Quincy district were superior to the other fuller's earth for muds used in drilling salt formations, although they were inferior to bentonite where the rocks drilled contained no salt water. However, the present trend in increased use of lower density muds, emulsion muds, and drilling with compressed air is likely to depress the demand for clays from this district for drilling mud (Haas, 1971, p. 5).

By 1950, significant quantities of fuller's earth were being used in making insecticides and fungicides, and the market for this use has grown at a rather uniform rate since then. In 1969, nearly 20 percent of the fuller's earth produced was used for insecticides and fungicides.

The use of fuller's earth for absorbent purposes began during the 1930's but did not expand significantly until World War II, which stimulated the use of fuller's earth as an absorbent for greases, oil, water, chemicals, and other undesirable substances on the floors of factories, filling stations, canning plants, aircraft hangers, decks and engine rooms of ships, and other installations. The product sold for this use is commonly known as absorbent granules. These granules are a porous material ordinarily weighing less than 30 pounds per cubic foot; most granules are $< 8$ mesh and $> 60$ mesh (U.S. standard-sieve sizes). Because of their light weight, size, porosity, and absorbent properties, these granules are suitable for many uses; and since World War II, many different markets for them have developed. They are now sold for litter and bedding for poultry, pets, and

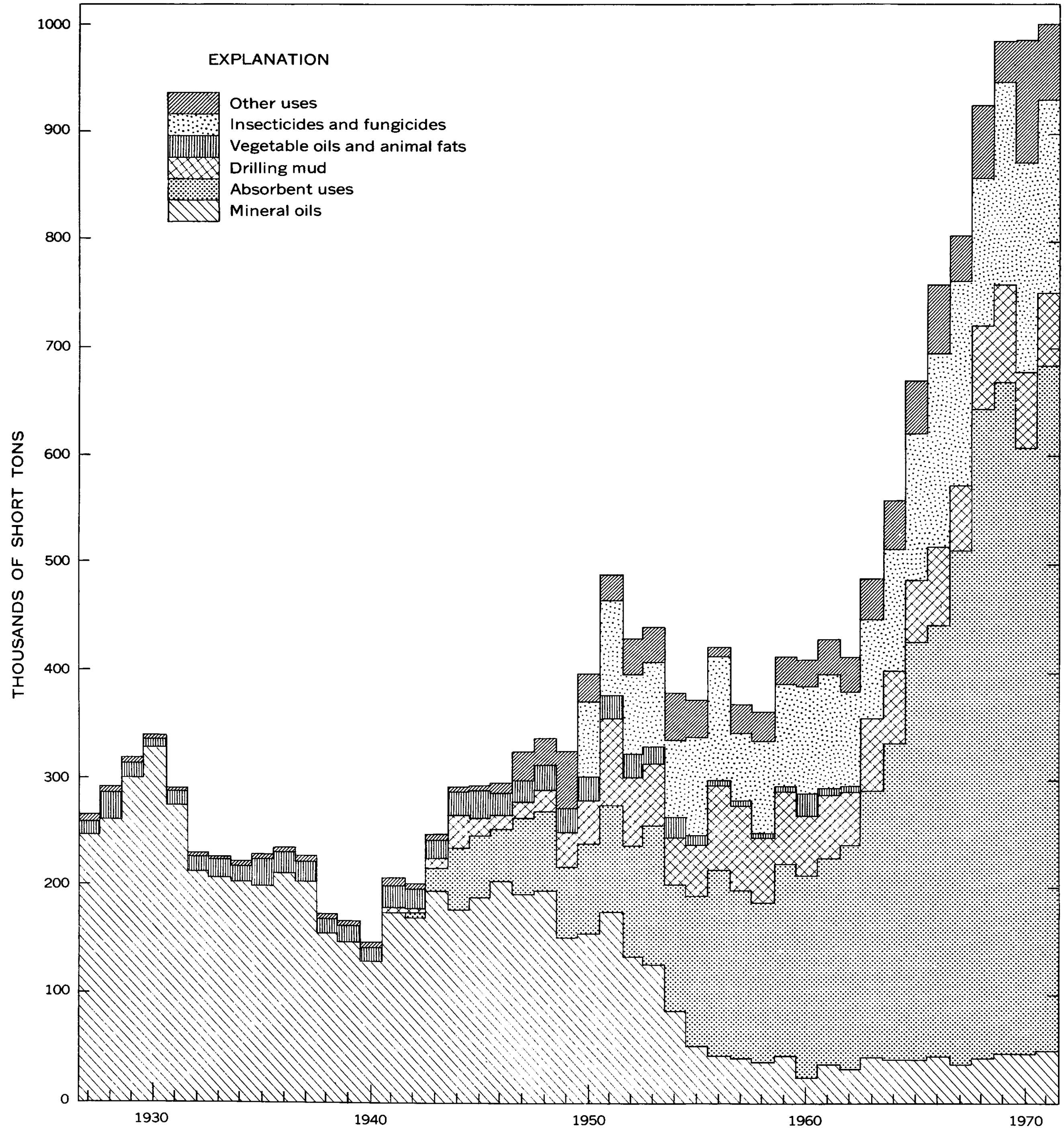



FIGURE 5.—Fuller's earth sold or used by producers for specified uses, 1927-71, compiled from U.S. Bureau of Mines Minerals Yearbooks.

other animals, as a soil conditioner for greenhouses and golf courses, and for other purposes. In 1971, approximately 680,000 tons of fuller's earth was sold for adsorbent uses; this tonnage was about two-thirds of the total fuller's earth produced in the United States that year.

The foregoing discussions apply only to those uses consuming sufficient quantities of fuller's earth to be classified separately by the U.S. Bureau of Mines in the Minerals Yearbooks. In addition, fuller's earth is or has been produced for many miscellaneous uses, such as pharmaceuticals designed to absorb toxins, bacteria, and alkaloids and used in treatment of dysentery; purifying water and dry-cleaning fluids; dry-cleaning powders and granules; the manufacture of NCR (no carbon required) multiple-copy paper, the manufacture of wallpaper; and extenders or fillers for plastics, paints, and putties. Fuller's earth mined at Ellenton (near Tampa), Fla., was used for making lightweight aggregate for the construction of concrete barges during World War II (Calver, 1957, p. 80; Greaves-Walker and others, 1951, p. 14, table 3). Still other uses of fuller's earth and its suitability for uses in new products were outlined by Haden (1963), Haden and Schwint (1967), and Haas (1970, 1971). Some reports also note that fuller's earth is used in making cement. Probably the basis of these reports is the mining of the Twiggs Clay near Clinchfield, Ga., north of the district, and its use in making portland cement. The fuller's earth is used mainly to obtain the desirable chemical composition in the clinker from which the cement is made. The classification of this clay as fuller's earth results from the fact that Twiggs Clay is mined for fuller's earth north of the district, near Macon Ga., and this formation is widely known in Georgia as a fuller's earth.

## PRODUCTION

Records of production of fuller's earth in the Meigs-Attapulgus-Quincy district are not available; however, the total output can be estimated on the basis of the national leadership of this district and the figures available for the total output of all districts in Georgia and Florida. These two States have led the Nation in domestic production of fuller's earth since 1895 (fig. 6). They produced 72 percent of the national total during the period 1895 through 1971, or 20.3 million tons valued at more than $375 million. The total fuller's-earth production of Georgia and Florida during this period was about 14.7 million tons, having a value of nearly $300 million. This value is higher than the national average, because in most years the palygorskite (attapulgite) fuller's earth from the southern part of the Meigs-Attapulgus-Quincy district sold for $2 to $4 a ton more than fuller's earth from other districts. Other fuller's-earth districts are presently active in both Georgia and Florida, and still others have been active intermittently in the past; therefore, the total production for Georgia and Florida does not apply directly to the Meigs-Attapulgus-Quincy district. However, this district has been the major fuller's-earth producer in these two States and has probably supplied 80 percent of the total for these States. On this assumption, the total fuller's earth produced in the Meigs-Attapulgus-Quincy district has been approximately 11.7 million tons, and the value probably has been more than $230 million.

The following companies operate eight plants producing fuller's earth in the Meigs-Attapulgus-Quincy district: Waverly Mineral Products Co., at Meigs, Ga.; Pennsylvania Glass Sand Corp., at Quincy, Fla. (operated under the name Floridin Co.), Havana, Fla. (formerly owned by Dresser Minerals Division of Dresser Industries), and Ochlocknee, Ga. (formerly owned by Thor Mining Co.); The Oil-Dri Corporation of America, at Ochlocknee, Ga. (opened in 1971, they also formerly operated a plant under the name of Cairo Production Co., near Cairo, Ga.); Cherokee Industries, at Ochlocknee, Ga. (opened in 1971); and both Minerals and Chemicals Division of Englehard Minerals and Chemicals Corp. and Milwhite Co., at Attapulgus, Ga. Fuller's-earth plants which have been dismantled were operated at Ochlocknee and Faceville in Georgia and at Jamieson, Midway, and a locality called Old Jamieson (Bay and Munyan, 1940b, p. 308), along the Seaboard Railway 2½ miles west of Mount Pleasant, in Florida. A few tons of fuller's earth was also produced 5 miles southeast of Chattahoochee, Fla., in the early 1900's.

## MINING

After a suitable fuller's-earth deposit has been proved by drilling and testing, the first step in mining is the removal of the overburden. Bulldozers and scrapers are used by all companies active in the district, and one company uses a large electrically powered walking dragline for much of its stripping. Thicknesses of overburden stripped range from a few feet to approximately 75 feet in most mines, but in some mines the maximum overburden removed along ridge lines is as much as 100 feet thick. Most of the overburden is so unconsolidated that it can be loosened with a bulldozer, but in the southern part of the district some of the overburden consists of limestone and cemented sandstone that must be blasted before removal with heavy equipment. In most mines, removal of overburden is done in panels, and after the earth in one panel is mined, the overburden from the next panel is dumped in the mined-out area. After stripping, the fuller's earth is loaded on trucks by dragline and hauled to the plant. In the early part of the century, mine trams were used for hauling, and some of the stripping was done by hydraulic methods, but neither technique has been used in recent years.

## PROCESSING

The raw fuller's earth as it is delivered to the plant contains approximately 50 percent volatile matter, and some of it contains as much as 10 percent undesirable impurities. The volatile matter is chiefly free and combined water. The processing of fuller's earth involves mainly crushing or slicing the crude clay, drying or firing to drive off the volatlie matter and improve the desired properties, grinding, grading by particle size, and packaging. According to Oulton (1965, p. 5), more than 90 different commercial grades and products, each with its own specific properties and applications, are made by varying the raw material and the processing. One plant uses an extruding process before drying the clay to improve the properties for certain products. In this process, the crushed clay is fed into a pug mill, and water is added to obtain the desired plasticity. The clay

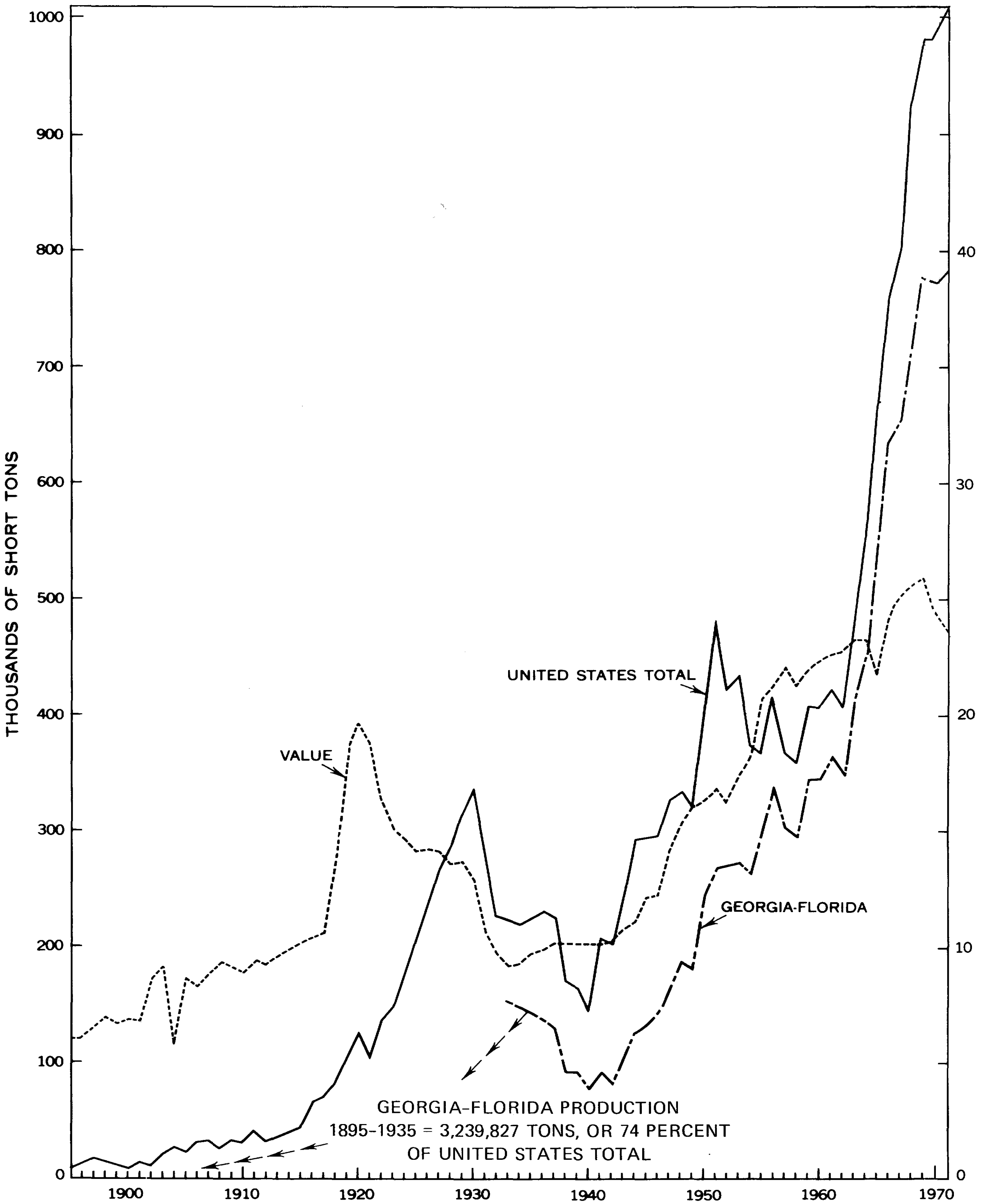



FIGURE 6.—National and Georgia-Florida production of fuller's earth and average value per ton, 1895-71, compiled from U.S. Bureau of Mines Minerals Yearbook.

is then extruded as rods approximately one-half inch in diameter.

Drying in most plants is done in gas- or oil-fired rotary dryers, which are as large as 10 feet by 65 feet, but one plant uses a fluid-bed-type dryer. The temperature at which the clay is dried ranges from 300 to 1,200° F in the different dryers, depending on the use of the product. The dried clay is ground in rod or other types of mills and sifted to yield a variety of granular and pulverized grades. Plants in the northern part of the district that produce mainly absorbent granules actually beneficiate their product by discarding the fines. This is possible because most of the impurities are in the sand and silt sizes and, therefore, are distinctly finer than the granular-size product. Plants in the southern part of the district, which produce many grades of pulverized fuller's earth as well as granular grades, commonly recycle their material and select their raw clay with considerable care. One of the products resulting from selective mining and processing is 95 percent finer than 10 microns in particle size; it is used for suspending agents and other purposes.

### OCCURRENCE

The fuller's-earth deposits are in a belt extending from near Meigs, Ga., to south of Quincy, Fla., a distance of approximately 50 miles (fig. 1). The deposits are in large lenses which locally form a discontinuous bed in the upper part of the Hawthorn Formation. Though the fuller's earth occurs throughout this belt, the deposits that have been mined most extensively are in the northern and southern parts of the district. Small mines have been operated in the central part in the past, but none have been active in recent years.

The fuller's-earth deposits are at rather uniform altitudes above sea level throughout the district, and this fact serves as a useful guide in prospecting. The deposits are highest along the solution escarpment in the western part of the district, where the top of the clay is at altitudes of 253 feet at the small abandoned mine near Faceville, Ga. (pl. 1), 260 feet at auger hole 13, and 243 feet at auger hole 6. The top of the fuller's earth is 200 to 240 feet above sea level in the northern part of the district and 160 to 190 feet where mined in the vicinity of Attapulgus, Ga. The altitude at the top of most clay mined in the vicinities of Quincy and Midway, Fla., is 130 to 150 feet, but in one core hole of the Florida Bureau of Geology, south of the mines (table 5, W7539), the top of a deposit, which may have been lowered by slumping, was penetrated at an altitude of 107 feet.

The deposits in the northern part of the district are thicker and more continuous than those in the southern part (fig. 7). The fuller's earth near Meigs and Ochlocknee, Ga., is as much as 60 feet thick, according to water-well records, and deposits 32 and 47 feet thick are mined (table 3, secs. 1 and 2). Deposits mined in the Attapulgus, Ga.-Quincy, Fla., parts of the district range from 7 to more than 10 feet thick (table 3, secs. 3-7). However, lenticular deposits in this part of the district overlap, and at places two layers of fuller's earth, each nearly 10 feet thick and separated by sandy beds as much as 11 feet thick, are mined. In a few places, three overlapping layers have been mined.

The lithologies of the fuller's earth in the two parts of the district are also quite different. In addition to the significant differences in clay-mineral composition, clay-pebble zones are common in the middle and upper parts of deposits near Meigs and Ochlocknee, Ga., but do not occur in the southern part of the district. The clay pebbles occur with quartz sand (table 3, secs. 1 and 2) in layers ranging from one-half inch to 3 inches in thickness. The pebbles are as much as 2 inches in longest dimension, but most are smaller. Most pebbles consist of the same type of clay that makes up more massive parts of the deposit, but several were found to be richer in attapulgite than the deposits that enclose them.

The position of the fuller's earth in the Hawthorn Formation and the kinds of beds above the deposits are quite different in the northern and southern parts of the district (fig. 7). In the northern part, the fuller's earth occurs either at the top of the Hawthorn Formation or just below the top, with only a few feet of clayey and sandy beds separating the fuller's earth from the overlying Miccosukee Formation (Hendry and Yon, 1967). In the southern part of the district, Hawthorn beds as much as 70 feet thick are present above the fuller's earth. These beds consist mainly of clayey sand, much of which is carbonate cemented, carbonate beds, and minor quantities of clay.

### MINERALOGY

The fuller's-earth deposits of the Meigs-Attapulgus-Quincy district are of variable mineral composition. A few of the purer deposits consist chiefly of one clay mineral and contain only minor amounts of other clay and nonclay minerals. Most deposits, however, are mixtures of clay minerals and contain several detrital, authigenic, and diagenetic nonclay minerals. Material of biogenic origin is abundant in some deposits.

#### CLAY MINERALS

*Palygorskite and sepiolite.*—Palygorskite (attapulgite) and sepiolite are complex magnesium silicate minerals having a fibrous crystal habit (fig. 8). These minerals commonly occur in close association and are so similar that some mineralogists (Bailey, 1972, p. 10-11) believe that intergrowths of even more complex structural variation may exist. Because of the close relationship, the name "hormite group" has been proposed for these minerals (Martin Vivaldi and Robertson, 1971, p. 255), but this name is yet to be widely accepted by mineralogists.

According to Bradley (1940, p. 406), palygorskite has

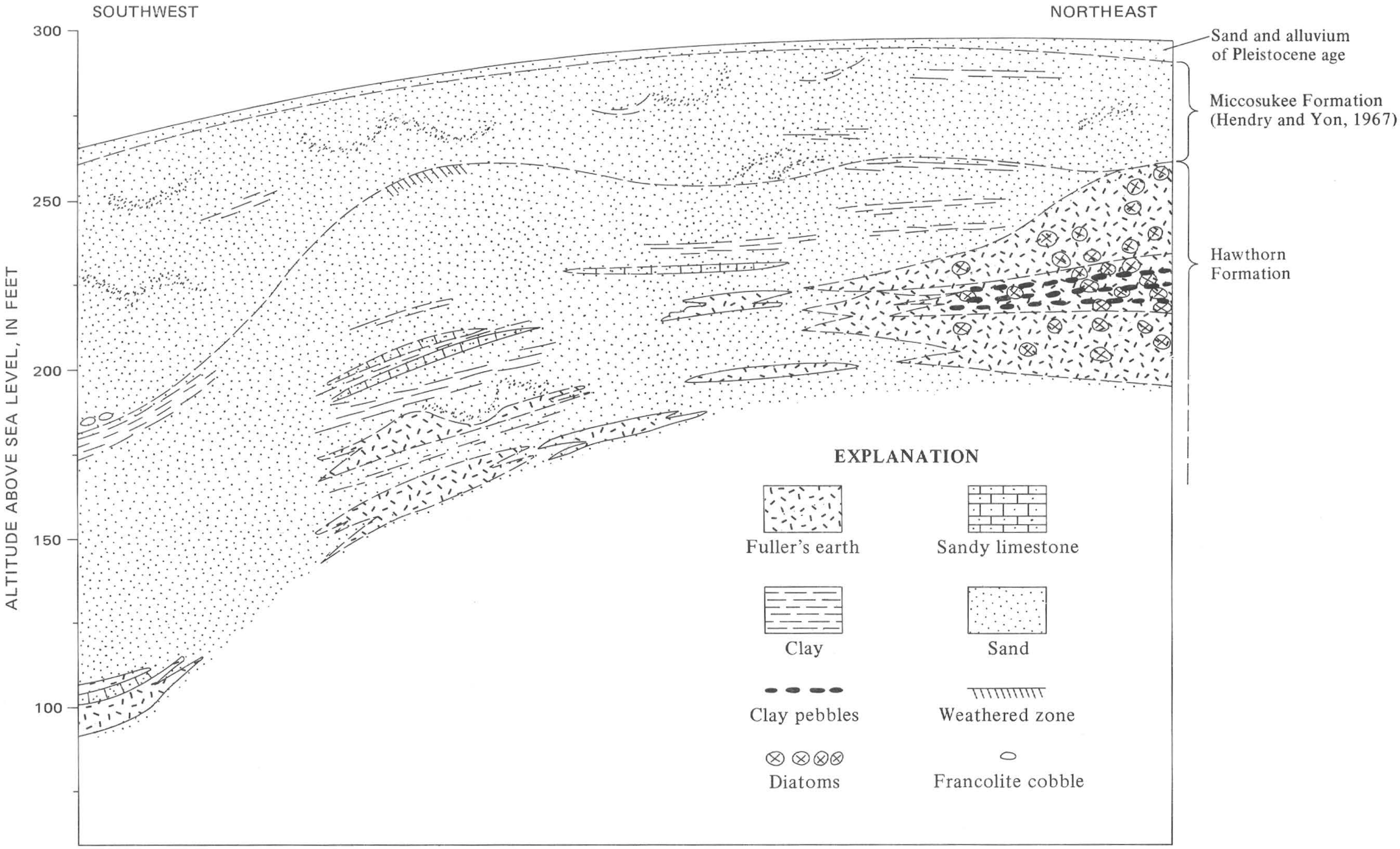



FIGURE 7.—Diagrammatic section of the rocks in the central part of the Meigs-Attapulgus-Quincy district.


FIGURE 8.—Electron micrograph of fuller's earth from mine C (pl. 1; table 3, sec. 3, bed 6).

an ideal formula of $(OH_2)_4(OH)_2Mg_5Si_8O_{20} \cdot 4H_20$, but $Al^{+3}$ substitutes for either $Mg^{+2}$ or $Si^{+4}$. The mineral consists of silica chains linked in amphibolelike structures and has both monoclinic and orthorhombic symmetry (Christ and others, 1969, p. 204). Sepiolite, $(Si_{12})(Mg_9)O_{30}(OH)_6(OH_2)_4 \cdot 6H_2O$, is similar to palygorskite, but it has extra silica tetrahedrons on the amphibole chain at regular intervals (Grim, 1968, p. 116), so that its unit cell is somewhat larger than that of palygorskite. Palygorskite in the fuller's earth is identified by its diagnostic X-ray reflections, the most prominent of which is at 10.4-10.5 A (pl. 2, *C-E*). The prominent X-ray reflection for sepiolite in these deposits occurs at a little less than 12 A. Differential thermal-analysis curves of whole samples of fuller's earth (fig. 9) varied so much that they are of little help in identifying and estimating the quantities of the various clay minerals in the fuller's earth. However, the samples rich in palygorskite have much stronger endothermic reactions at about 175°C (fig. 9, *C-E*) than those rich in montmorillonite (fig. 9, *A-B*). The curves of the palygorskite-rich samples also have prominent exothermic reactions above 1,000° C, which probably are related to the crystallization of enstatite, cristobalite, and cordierite, the chief products of the high-temperature transformation (Huggins and others, 1962, table 6).

Palygorskite is most abundant in the Attapulgus-Quincy part of the district, where some fuller's-earth deposits consist of 70 to 80 percent polygorskite (pl. 2*E*, table 1, col. 8). It rarely makes up more than 20 percent of the fuller's earth mined in the vicinities of Meigs and Ochlocknee, but it was found to be abundant in a few localities in the central part of the district where no mining has been done (table 4, auger holes 6-9). Sepiolite is rare, if not absent, in the southern part of the district, but it forms as much as 10 percent of deposits in the northern part. Scattered deposits containing minor quantities of sepiolite were also penetrated in augering in the central part of the district (table 4).

*Montmorillonite.*—Montmorillonite is a clay mineral consisting of two sheets of silica tetrahedra and a central sheet of alumina octahedra. The theoretical formula of this mineral, following calculations of Ross and Hendricks (1945, p. 23), is generally considered to be

$$(OH)_4Si_8(Al_{3.34}Mg_{0.66})O_{20}.$$
$$\downarrow$$
$$Na_{0.66}$$

The arrow indicates the group having a deficiency of charge which requires an additional exchangeable ion external to the silica sheet. Here this change is shown as balanced by sodium. The differential thermal-analysis curves of montmorillonite fuller's earth (fig. 9, *A-B*) indicate by the endothermic reaction at about 175°C that the exchangeable ion on montmorillonite in the Meigs-Attapulgus-Quincy district is probably $Ca^{+2}$ instead of $Na^+$, and $H^+$ may be the balancing ion in some of the weathered parts of deposits.

*Kaolinite.*—Kaolinite, $(OH)_8Si_4Al_4O_{10}$, occurs in the upper, weathered part of many deposits. Small quantities of this mineral were found in the upper parts of deposits mined in the northern part of the district. It

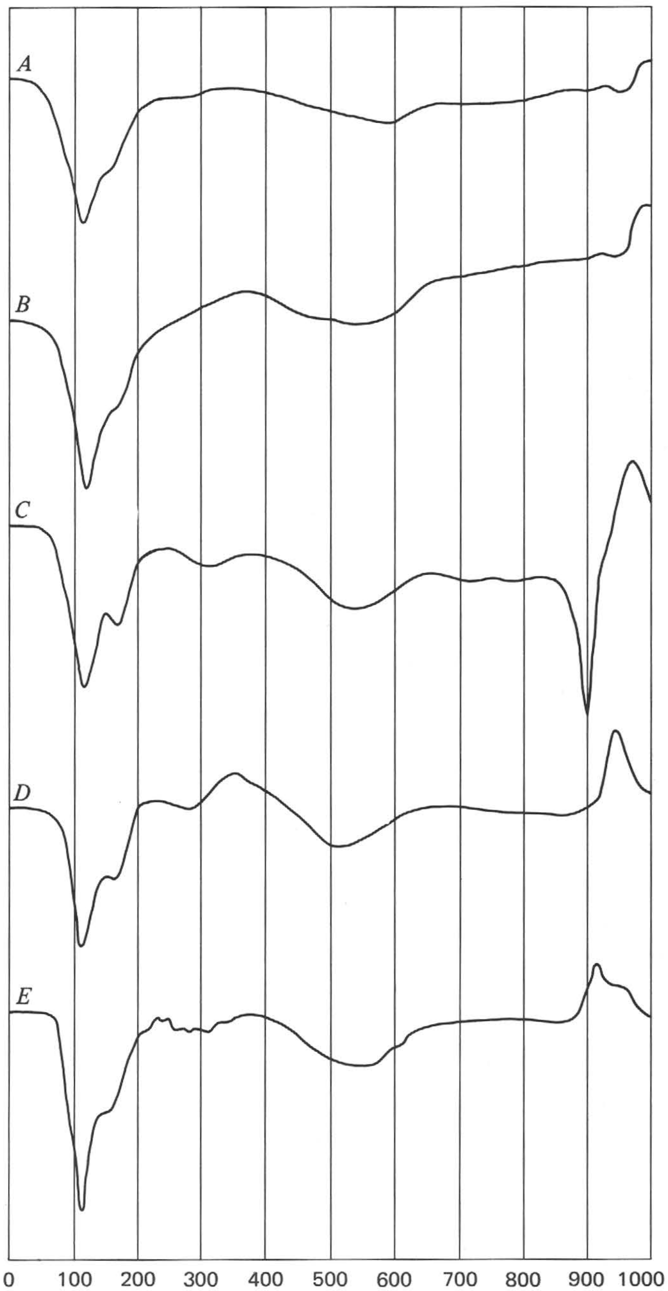



FIGURE 9.—Differential thermal-analysis curves of fuller's earth. *A*. Sample of section 30 ft 6 in. thick, from mine A (pls. 1,2*A*; table 3, sec. 1, beds 4, 7-9; table 1, col. 4). *B*. Sample of section 14 ft 8 in. thick, from mine B (pl. 1, 2*B*; table 3, sec. 2, beds 10-12; table 1, col. 5). *C*. Sample of section 5 ft thick, from mine C (pl. 1, 2*C*; table 3, sec. 3, bed 6; table 1, col. 6). *D*. Sample of section 3.5 ft thick, from mine C (pl. 1, 2*D*; table 3, sec. 3, bed 7; table 1, col. 7). *E*. Sample of section 7 ft 2 in. thick, from mine G (pl. 1, 2*E*; table 3, sec. 7, bed 13; table 1, col. 8).

also is common in the upper part of deposits in the central part of the district (table 4) and was found in samples from several outcrops.

#### DETRITAL NONCLAY MINERALS

*Quartz.*—Quartz is the most abundant detrital mineral in the fuller's earth. It ranges in abundance from trace amounts to so much that the fuller's earth might properly be called a clayey sand, and very sandy deposits have no value. Most quartz is in rounded to subrounded frosted grains, but angular clear grains occur in some deposits. Grain size of most of the quartz ranges from silt to medium sand, and very little of it is in clay-sized particles.

*Feldspar.*—This mineral is the second most common detrital mineral in the fuller's earth. It made up as much as 20 percent of one impure deposit in the central part of the district (table 4), but it is rare or absent in most deposits mined. Most of the feldspar is in subrounded fine- to medium-sized grains, but some angular grains of the same size range are also present.

*Heavy minerals.*—Several heavy minerals, typical of sedimentary suites in Miocene rocks of the Coastal Plain are present here only in trace amounts, include garnet, sillimanite, rutile, and ilmenite.

#### AUTHIGENIC AND DIAGENETIC NONCLAY MATERIALS

*Calcite.*—Calcite, $CaCO_3$, in addition to that of biogenic origin, occurs in concretions, discrete crystals, and scattered veinlets and as desiccation-crack fillings in the fuller's earth. Most concretions are small, but a few are a foot or more across and 6 to 8 inches thick. The individual calcite crystals, which are scattered through some deposits, ordinarily are sufficiently large to be observed in hand specimen, and some are as much as one-fourth inch across. The veinlets are rarely as much as one-half inch thick, and many are paper-thin fillings along joints. The dessication-crack fillings are as much as 1 inch thick and extend downward from the top of one deposit for 1½ feet (table 3, sec. 6, bed 5). All the forms of calcite are generally rare in most of the deposits mined, but they are so abundant locally that parts of some deposits must be bypassed or discarded in mining. Excessive calcite found in evaluation drilling is one of the principal reasons why many deposits have little value.

The discrete crystals, veinlets, desiccation-crack fillings, and some concretions are virtually pure calcite. Some concretions, however, contained appreciable quantities of dolomite mixed with the calcite, and many of the concretions are quite sandy.

*Carbonate-fluorapatite.*—Trace amounts of carbonate-fluorapatite, a phosphate mineral described by Altschuler, Clarke, and Young (1958), occur in the fuller's earth deposits, principally as animal remains and in pelletal form. Most of these phosphatic materials are in the sand and silt lenses which are common in some deposits, but scattered phosphatic materials have been found in the fuller's earth. The animal remains are mainly teeth of shark and ray and fragments of bones of vertebrates. The phosphate pellets are commonly light gray, gray, tan, dark brown, or black and have a shiny luster. The pellets are rarely larger than coarse-sand size.

*Dolomite.*—White chalky dolomite, $CaMg(CO_3)_2$, occurs as thin beds and concretionlike algal heads in the fuller's earth in the central and southern parts of the district. The beds range from 1 to 8 inches in thickness, and the concretions are as much as 1½ feet in longest dimension. They were identified by the presence of growth layers in some of them, which were observed after cutting and polishing. Algal heads commonly are bulbous, and many resemble cauliflower heads. Three samples of dolomite beds (table 3, sec. 4, bed 15; sec. 5, bed 30; and sec. 6, bed 8; table 5, W7539) were examined by X-ray methods and were found to be eight to nine parts dolomite and one to two parts palygorskite. No calcite was associated with any of this dolomite. The dolomite appeared massive and dense in hand specimen; but when examined with a petrographic microscope it was found to consist of rhombohedral crystals ranging in size from about 1$\mu$m to 15$\mu$m. Most of these grains have isotropic nuclei which are too small to identify (fig. 10).

*Opal.*—Clayey opal concretions, which are ovoid and reach a maximum of 6 inches in longest dimension, occur in the fuller's earth at a few places in the northern

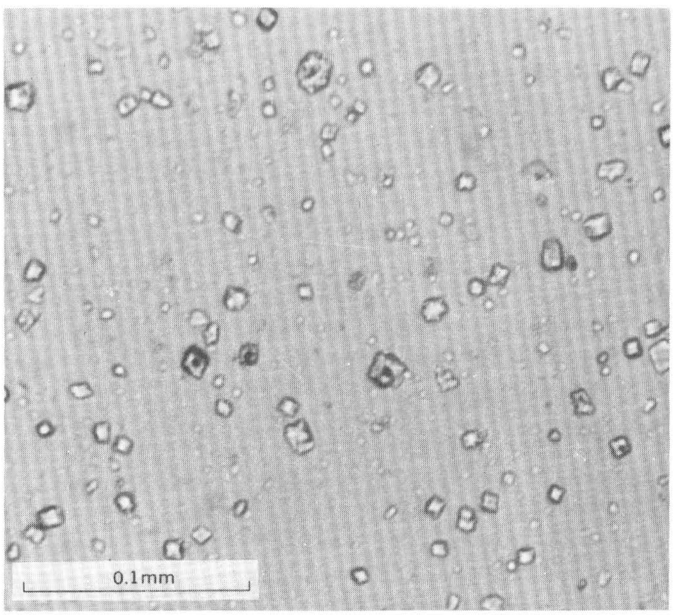



FIGURE 10.—Photomicrograph of powder mount of dolomite in fuller's earth (table 3, sec. 5, bed 30).

part of the district. They are so abundant in parts of one deposit that the fuller's earth is discarded in mining. These opal concretions appear similar to the clay that contains them but are much harder. Two of these concretions examined by X-ray methods were approximately one-fourth clay of the same type as that forming the deposits. No prominent reflections were present in the diffraction trace, which is characteristic of the noncrystalline opal. One of these opal concretions was examined by electron microscopy by Pollard, Weaver, and Beck (1971); they found that the silica is mainly in the form of spheres 0.1-.9$\mu$m in diameter. Some of these spheres coalesce to form rods, sheets, and blocks. The origin of at least some of the spheres appears to be related to the dissolution of diatoms or other siliceous fossils.

*Material of biogenic origin.*—Trace amounts of calcite grains, which are mainly rounded shell fragments, occur in some deposits in the central part of the district. Fish teeth also have been found in fuller's earth, but they are rare. Diatoms (fig. 11) are so abundant in the northern part of the district that some layers could be considered a clayey diatomaceous earth. Diatoms are rare in the southern part, and those that are present are poorly preserved and show evidence of solution, suggesting that they may once have been more abundant in this part of the district, too. Silicoflagellates and sponge spicules are common in the fuller's earth in the northern part of the district but are rare in the southern part.

## CHEMICAL COMPOSITION

The fuller's earth consists chiefly of silicon,

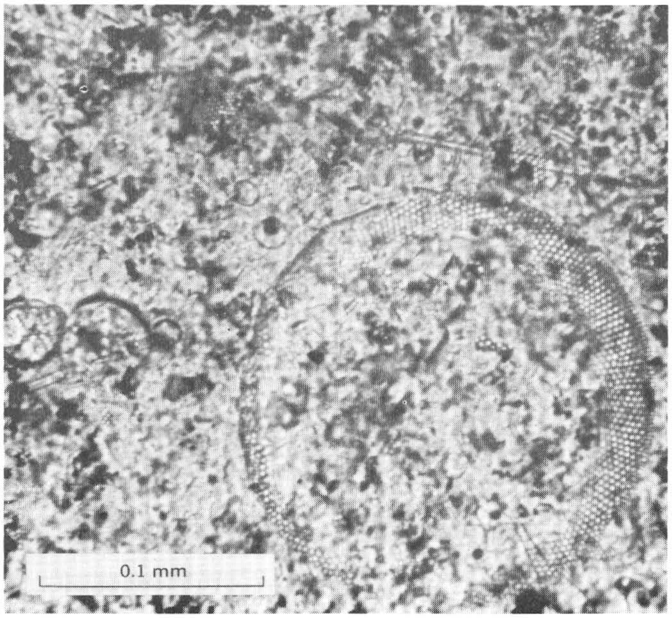



FIGURE 11.—Photomicrograph of a thin section of fuller's earth (table 3, sec. 2, bed 10), showing partly dissolved diatoms.

aluminum, magnesium, and iron oxides, according to analyses by the U.S. Geological Survey (table 1) and from other sources (Kerr and others, 1950, p. 57-58; Hagner, 1939, table 4; Huggins and others, 1962, table 1; Bradley, 1940, table 1; Grim, 1968, p. 582; and Ross and Shannon, 1926, table 2). Silica contents range from 51.3 to a little more than 61 percent. Most of the silica is in the clay minerals, but part is quartz impurities, and probably some is in opal or other forms of noncrystalline silica. Alumina contents range from 7.9 to 14.8 percent. Ordinarily alumina is less abundant in parts of deposits rich in palygorskite and sepiolite, and it is most abundant in the deposits which are chiefly montmorillonite but contain kaolinite. Percentages of magnesia range from 1.7 to 13.4 percent; this oxide occurs in inverse relationship to alumina, being most abundant in the deposits rich in palygorskite. Where palygorskite is abundant, the fuller's earth ordinarily contains more than 8 percent magnesia. Magnesium contents also vary vertically in many deposits, the lower part containing more of this element (table 1, sample 3) than the upper part (table 1, sample 1). The $Fe_2O_3$ contents of the fuller's earth analyzed range from 2.9 to 6.76 percent, and only very minor quantities of FeO are present. Much of the iron is apparently in the clay minerals and mineral impurities.

Thirteen minor elements in the fuller's earth were analyzed by quantitative spectrographic methods, and 22 elements were looked for but not found (table 2). All the samples analyzed contain more than 100 ppm (parts per million) barium, chromium, and zirconium, and one sample contains 160 ppm vanadium. Two samples (table 2, samples 4 and 5) from the northern part of the district contain considerably more barium than those from the southern part. No other trends in the distribution of minor elements were apparent.

## ORIGIN

A completely satisfactory explanation of the origin of the fuller's earth in the Meigs-Attapulgus-Quincy district has never been found, despite the work leading to this report and considerable research and speculation by other geologists and mineralogists on these deposits and similar ones elsewhere. Clearly, the origin of the deposits is related to the origin of the dolomite and phosphate minerals that occur in the fuller's earth, and the formation of these to minerals has also been difficult for geologists to understand. One of the principal difficulties is that the similar clay minerals palygorskite and sepiolite are present in the deposits in fine fibrous particles that could not have withstood transportation and therefore must have formed in place. The other clay minerals, however, mainly montmorillonite and kaolinte, that are present in parts of the deposits could have been introduced at the time of deposition, as were quartz sand and other detrital minerals.

**TABLE 1.**—*Chemical analyses and mineral estimates of fuller's earth, opal, and carbonate rock from the Meigs-Attapulgus-Quincy district*

[Samples 1-3 and 11-13 analyzed by P. Elmore, I. Barlow, S. Botts, and G. Chloe; 4-10 analyzed by P. Elmore, S. Botts, J. Kelsey, G. Chloe, H. Smith, J. Glenn, and L. Artis, U.S. Geol. Survey, using rapid chemical methods similar to those described by Shapiro and Brannock, (1956). Tr., trace]

| | Fuller's earth, grab samples | | | Fuller's earth, channel samples | | | | | Opal | | Dolomitic limestone | | Limestone |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample<br>Lab. No. | 1<br>158768 | 2<br>158769 | 3<br>158770 | 4<br>W172499 | 5<br>W172498 | 6<br>W172501 | 7<br>W172500 | 8<br>W172502 | 9<br>W172495 | 10<br>W172496 | 11<br>158771 | 12<br>158772 | 13<br>158773 |
| | | | | | | | **Chemical analyses (in weight percent)** | | | | | | |
| $SiO_2$ | 61.0 | 55.6 | 55.1 | 59.3 | 59.7 | 52.0 | 55.1 | 52.4 | 75.8 | 75.4 | 31.7 | 53.2 | 7.0 |
| $Al_2O_3$ | 14.8 | 11.6 | 9.2 | 11.8 | 12.2 | 9.0 | 10.5 | 10.2 | 3.7 | 4.5 | 5.2 | 3.4 | .86 |
| $Fe_2O_3$ | 4.6 | 4.0 | 3.0 | 3.4 | 3.4 | 2.9 | 3.1 | 3.4 | .41 | 1.0 | 1.4 | .63 | .22 |
| FeO | .11 | .07 | .14 | .44 | .44 | .20 | .24 | .16 | .48 | .44 | .14 | .13 | .08 |
| MgO | 1.7 | 7.1 | 9.5 | 4.4 | 5.4 | 9.1 | 8.8 | 7.3 | 2.7 | 3.0 | 12.6 | 7.9 | .67 |
| CaO | 1.0 | 1.0 | 1.6 | 1.3 | 1.2 | 4.3 | 1.4 | 4.6 | 1.7 | 1.2 | 17.1 | 11.9 | 49.8 |
| $Na_2O$ | .14 | .07 | .06 | .23 | .22 | .07 | .05 | .08 | .07 | .05 | .12 | .10 | .06 |
| $K_2O$ | 1.1 | .77 | .69 | .99 | .99 | .63 | .69 | .89 | .27 | .41 | .98 | .70 | .10 |
| $H_2O$ | 14.9 | 17.9 | 19.1 | ---------- | ---------- | ---------- | ---------- | ---------- | ---------- | ---------- | 6.8 | 4.2 | 1.2 |
| $H_2O-$ | ---------- | ---------- | ---------- | 7.9 | 4.6 | 9.0 | 9.7 | 8.8 | 9.9 | 7.5 | ---------- | ---------- | ---------- |
| $H_2O+$ | ---------- | ---------- | ---------- | 8.6 | 10.2 | 8.9 | 9.1 | 8.0 | 3.4 | 4.7 | ---------- | ---------- | ---------- |
| $TiO_2$ | .75 | .52 | .40 | .50 | .50 | .40 | .43 | .46 | .13 | .22 | .18 | .19 | .03 |
| $P_2O_5$ | .10 | .40 | .91 | .86 | .59 | .92 | .62 | 2.4 | .89 | .75 | .04 | .23 | .02 |
| MnO | .04 | .02 | .02 | .06 | .03 | .04 | .03 | .09 | .02 | .04 | .02 | .03 | .04 |
| $CO_2$ | .07 | .08 | .17 | .12 | .24 | 2.3 | .18 | .22 | .08 | .05 | 24.0 | 16.3 | 39.1 |
| Sum | 100 | 99 | 100 | 100 | 100 | 100 | 100 | 99 | 100 | 99 | 100 | 99 | 99 |
| Loss on ignition | ---------- | ---------- | ---------- | 16.2 | ---------- | ---------- | ---------- | ---------- | ---------- | ---------- | ---------- | ---------- | ---------- |
| | | | | | | | **Mineral estimates (in parts of 10)** | | | | | | |
| Palygorskite | | | | 2 | 1 | 6 | 5 | 8 | 1 | 1 | ---------- | ---------- | ---------- |
| Sepiolite | | | | Tr. | Tr. | 1 | ---------- | Tr. | ---------- | ---------- | ---------- | ---------- | ---------- |
| Montmorillonite | | | | 5 | 5 | ---------- | 2 | ---------- | ---------- | ---------- | ---------- | ---------- | ---------- |
| Kaolinite | | | | Tr. | Tr. | ---------- | Tr. | ---------- | ---------- | ---------- | ---------- | ---------- | ---------- |
| Quartz | | | | 3 | 3 | 1 | 2 | 2 | 2 | 2 | ---------- | ---------- | ---------- |
| Feldspar | | | | Tr. | ---------- | ---------- | ---------- | ---------- | ---------- | ---------- | ---------- | ---------- | ---------- |
| Calcite | | | | ---------- | ---------- | 1 | ---------- | ---------- | ---------- | ---------- | ---------- | ---------- | ---------- |
| Dolomite | | | | ---------- | ---------- | 1 | 1 | ---------- | ---------- | ---------- | ---------- | ---------- | ---------- |
| Fluorapatite | | | | ---------- | Tr. | Tr. | ---------- | Tr. | ---------- | ---------- | ---------- | ---------- | ---------- |
| Opal | | | | ---------- | ---------- | ---------- | ---------- | ---------- | 7 | 7 | ---------- | ---------- | ---------- |

**SAMPLE LOCALITIES**

1. 2 ft. below top of 13-ft.-thick section in pit of Dresser Minerals Division of Dresser Industries, S½NE¼ Sec. 16, T. 3 N., R. 2 W., Gadden County, Fla.; collected by L.R. Gremillion, 1961.
2. Same as 1, 5-6 ft. below top of fuller's earth.
3. Same as 1, 11 ft. below top of fuller's earth.
4. Composite sample, section 30 ft. 6 in. thick, from mine A (pl. 1; table 3, sec. 1, beds 4, 7-9); collected April 1968.
5. Composite sample, section 14 ft. 8 in. thick, from mine B (pl. 1; table 3, sec. 2, beds 10-12); collected April 1968.
6. Section 5 ft. thick, from mine C (pl. 1; table 3, sec. 3, bed 6); collected April 1968.
7. Section 3 ft. 6 in. thick, from mine C (pl. 1; table 3, sec. 3, bed 7); collected April 1968.
8. Composite sample, section 7 ft. 2 in. thick, from mine G (pl. 1; table 3, sec. 7, bed 13); collected April 1968.
9. Fresh, light-yellowish-gray, brecciated; chunks exposed in field 1.7 miles south of Cairo, Ga.; collected May 1969.
10. Same as 9, but weathered to a very light gray.
11. In Tampa Limestone, exposed in ditch on south side of road west of brick plant, SE¼SW¼ sec. 4, T. 3 N., R. 6 W., Gadsden County, Fla; collected by L.R. Gremillion, 1961; probably a grab sample.
12. 7.4 ft. thick, in Tampa Limestone, exposed in borrow pit east of Apalachicola River, Chattahoochee, Fla. (bed 2 of Gremillion, 1965 b, p. 140; bed 9 of Olson, 1966, p. 70); collected by L.R. Gremillion, 1961
13. 4 ft. 6 in. thick, in Tampa Limestone, same locality as 12 (bed 7 of Gremillion, 1965 b, p. 140; bed 13 of Olson, 1966, p. 69); collected by L.R. Gremillion, 1961.

The explanation is further complicated because some of the characteristics of deposits may have originated either penecontemporaneously, by diagenetic changes after overlying beds were deposited, or from deep weathering related to the present surface. Another problem is whether all deposits throughout the district are the same age. The deposits in the northern part of the district differ considerably from those in the southern part in mineralogy, abundance of diatoms, stratigraphic position with respect to the top of the Hawthorn Formation (fig. 7), and altitude above sea level. These differences suggest that the deposits are younger in the northern part, that they are progressively older to the south, and that minor changes in environments of deposition took place during the formation of deposits in the district. However, all these different characteristics may have resulted from geologic factors other than age and environment of deposition.

Palygorskite and the clay and nonclay minerals associated with it occur in many different types of rocks in various parts of the world. Palygorskite and sepiolite have been found in rocks ranging in age from Carboniferous to Holocene (Hathaway and others, 1970, p. E20). Most of the occurrences are in sedimentary rocks of Tertiary age, which were deposited in marine en-

TABLE 2.—*Quantitative spectrographic analysis for minor elements in fuller's earth and opal*

[J.D. Fletcher, U.S. Geol. Survey, analyst. Preheating of samples to drive off the water before arcing was necessary to keep them in the electrodes; therefore, volatile elements may have been lost. Looked for but not found: Ag, As, Au, Be, Bi, Cd, La, Mo, Nb, Pb, Pd, Pt, Sb, Sn, U, W, Zn, Ce, Ge, Ta, Th, and Tl. Sample locations are given in table 1. Analyses, in parts per million]

| Sample Lab. No. | Fuller's earth, channel samples | | | | | Opal | |
|---|---|---|---|---|---|---|---|
| | 4 W172499 | 5 W172498 | 6 W172501 | 7 W172500 | 8 W172502 | 9 W172495 | 10 W172496 |
| B | < 20 | 30 | <20 | < 20 | < 20 | < 20 | < 20 |
| Ba | 200 | 230 | 110 | 130 | 150 | 100 | 100 |
| Co | 15 | 14 | 7 | 6 | 6 | 5 | 6 |
| Cr | 100 | 140 | 150 | 110 | 170 | 68 | 89 |
| Cu | 13 | 20 | 12 | 15 | 14 | 5 | 8 |
| Ni | 26 | 32 | 16 | 15 | 48 | 14 | 15 |
| Sc | 14 | 15 | 13 | 13 | 16 | < 4 | 8 |
| Sr | 40 | 59 | 61 | 48 | 120 | 31 | 21 |
| V | 70 | 80 | 100 | 73 | 160 | 40 | 100 |
| Y | 30 | 40 | 40 | 30 | 40 | 30 | 30 |
| Zr | 110 | 150 | 110 | 140 | 170 | 40 | 70 |
| Ce | 10 | 10 | 10 | 10 | 10 | < 10 | <10 |
| Yb | 2 | 3 | 2 | 2 | 3 | 2 | 2 |

vironments, but in some places these minerals are associated with rocks and minerals that formed under arid conditions, in saline environments, by surficial weathering, and by hydrothermal activity. An association of palygorskite, montmorillonite, and phosphate minerals in marine beds has been noted in several places in the Coastal Plain of Southeastern United States (Espenshade and Spencer, 1963, p. 18-21; Cathcart, 1963a, p. 41); Heron and Johnson, 1966, p. 59-62) and in Miocene rocks underlying the Blake Plateau east of Florida (Hathaway and others, 1970; Weaver, 1968). Similar associations have been noted in Senegal (Capdecomme and Kulbicki, 1954, p. 500-503) and in Dahomey (Slansky and others, 1959). Palygorskite and sepiolite associated with crystobalite and volcanic ash are found in samples from Eocene beds penetrated by drill holes at several places in the Atlantic Ocean (Rex, 1970, p. 330), and sepiolite and clinoptilolite occur in rocks on the Mid-Atlantic ridge (Hathaway and Sachs, 1965). Palygorskite occurs in layers in bentonite in the U.S.S.R. (Ovcharenko and others, 1967, p. 39-40) and is associated with illite and kaolinte in marine deposits in India (Siddiqui, 1968, p. 64-65). Palygorskite has also been formed by the weathering of montmorillonite, which in turn has weathered from basalt (Heystek and Schmidt, 1953, p. 99) and from clay minerals found during the weathering of basalt in Australia (Loughnan, 1960, p. 49-50). Veins of palygorskite in Morocco are thought to have formed by hydrothermal activity (Caillere, 1951, p. 697), and deposits in the Shetland Islands have a similar origin (Stephen, 1954, p. 478). An association of sepiolite with diatomite has recently been found in samples dredged from the Santa Cruz basin off of California (Fleischer, 1972). This sepiolite not only occurs with diatoms, as does the sepiolite in the northern part of the Meigs-Attapulgus-Quincy district, but both occurrences are in rocks of similar geologic age. The sepiolite deposits at Vallecas and elsewhere in the Tagus basin in central Spain occur in an evaporite facies of Tertiary age (International Clay Conference, 1972). They therefore formed under conditions somewhat similar to those in which the fuller's earth of the Meigs-Attapulgus-Quincy district are thought to have formed.

Montmorillonite is the most abundant mineral in some of the fuller's-earth deposits. Part of it apparently formed by the weathering of palygorskite, but montmorillonite occurs elsewhere in several different types of rocks, and some in these fuller's-earth deposits may have been deposited nearly in its present form. The purest and best known montmorillonite occurring elsewhere is in bentonite, a clay formed by the alteration of fine-grained minerals and glass in volcanic ash or tuff. Montmorillonite also forms by hydrothermal processes and by weathering of certain types of igneous rocks, particularly in areas of low rainfall or where drainage is restricted.

Kaolinite is abundant in the upper parts of fuller's-earth deposits under shallow overburden, particularly in the northern part of the district. The gradation of kaolinite downward into montmorillonite in fuller's-earth deposits near the surface suggests that it formed by weathering of this mineral, but some of the kaolinite could have been deposited virtually in its present form. Elsewhere, kaolinite occurs in many different geologic environments. The extensive kaolin deposits in central Georgia have been transported. Kaolinite is probably most common throughout the world as a weathering product of various types of rocks (Keller, 1970, p. 797-799). It also is a common product of hydrothermal alteration.

Several theories have been advanced to explain the origin of palygorskite and sepiolite. Longchambon (1935) thought they form by the alteration of amphibole and pyroxene, presumably because these minerals also have elongate chainlike atomic structures. Kerr (1937, p. 549), before the structure of palygorskite was understood, favored the idea that the "Attapulgus clay" was a form of montmorillonite resulting from the weathering of crystalline rocks of the highlands. Millot and his coworkers (Millot and others, 1957, 1963; Millot, 1962, 1967; Lucas, 1968, p. 161) believed in a process of neoformation which is apparently similar to halmyrolysis for the origin of palygorskite and sepiolite. According to this idea, these minerals form in a marine, or even a certain restricted nonmarine environment from silica resulting from weathering in source areas and from magnesium present in the environment of formation, which presumably must be concentrated or selectively extracted. Rateev (1965, p. 179) concluded that conditions favorable for sepiolite formation are high carbon concentration, high pH, and high $SiO_2$ activity. He noted that such conditions are most likely to exist in desiccating lakes in arid regions. McClellan (1964, p. 91-96) advanced the idea that palygorskite in Georgia and Florida formed from the silica dissolved from diatoms and magnesium introduced by sulfate spring water. However, only minor movement of ground water has occurred, inasmuch as the carbonate rocks associated with the fuller's earth show little evidence of solution; moreover, some of the older ones that are cavernous contain no large deposits of fuller's earth.

The idea that the fuller's earth in the Meigs-Attapulgus-Quincy district and similar clay in other places in Southeastern United States formed from volcanic ash was considered by Grim (1933), who studied samples from several localities. Such an origin for fuller's-earth-type clays in Levy and Citrus Counties, Fla., was also considered by Vernon (1951, p. 187), who attributed to C. S. Ross the observation that these particular deposits consist chiefly of montmorillonite and opal and have all the characteristics of bentonite, except that no volcanic shards have been found in them. Heron and Johnson (1966, p. 61) reached similar conclusions for Miocene clays in Beaufort County, S.C., as did Espenshade and Spencer (1963, p. 20) for fuller's earth in peninsular Florida. Gremillion (Buie and Gremillion, 1963, p. 25; Gremillion, 1965b, p. 89-91) argued that the palygorskite in the Meigs-Attapulgus-Quincy district formed from volcanic ash, but he supplied little supporting evidence for this idea. Hathaway, McFarlin, and Ross (1970, p. E20-E22) believed that palygorskite and sepiolite in Miocene rocks on the submarine Blake Plateau east of Florida formed from ash, and they cited the presence of a zeolite mineral in these rocks and abundant volcanic ash in Oligocene beds to support this idea. Hathaway and Sachs (1965, p. 865) thought sepiolite in marine sediments on the Mid-Atlantic ridge also formed from ash. Some of the palygorskite penetrated by drilling in the Atlantic Ocean, which was studied by Rex (1970), is closely associated with volcanic ash and zeolites, but in summarizing the results of these findings (Peterson and others, 1970, p. 417), the conclusion was reached that the source of the magnesium required to form palygorskite is uncertain.

### ENVIRONMENT OF DEPOSITION

The fuller's earth in the Meigs-Attapulgus-Quincy district formed in a restricted shallow marine environment, a conclusion supported by several geologic observations. The evidence for marine conditions includes the abundant diatoms, interbedded dolomite and limy layers, the shark and ray teeth, and the phosphate minerals in the fuller's earth. The characteristics establishing shallow-water conditions, most of which were also recognized by Gremillion (1965a) and Weaver and Beck (1972), include the following: (1) Abundant beds of clay pebble conglomerate in the fuller's earth in the northern part of the district; (2) shallow-water diatom fauna in several deposits; (3) desiccation or mud-crack fillings observed in the upper part of one deposit (table 3, sec. 6, bed 5); (4) channel-fill deposits of sand and gravel which cut at least one deposit of fuller's earth (table 3, sec. 5, bed 21); (5) *Callianassa* borings in some deposits and in the clastic channel-fill deposit; (6) the abundant detrital sand in some deposits; (7) the dolomite beds, algal heads, and concretions and limy layers; and (8) the petrified wood and vertebrate fossils in beds overlying fuller's earth at Midway and Quincy, Fla. The shallow-water indications also agree with a much earlier conclusion by Gardner (1926, p. 1) that the prolific Alum Bluff molluscan fauna was controlled by a progressively falling temperature and a gradual subsidence of the sea.

The dolomite and filled mud cracks establish that during at least part of their history some fuller's-earth deposits were above sea level in an area of a mudflat or shallow lagoon. An intratidal or supratidal origin of the dolomite is indicated by its pronounced similarity to dolomite forming penecontemporaneously in a mudflat or sebkha along the Persian Gulf (Illing and others, 1965), in supratidal areas in the Bahamas (Shinn and others, 1965), and in very restricted supratidal lagoons in southwestern Australia (von der Borch and others, 1964). The dolomite in both the fuller's-earth deposits and in the sebkha along the Persian Gulf is very fine grained and occurs in separate rhombs that are unlikely to have formed where any spatial restriction by enclosing lithified sediments was present. The nuclei in many of the dolomite rhombs in the fuller's earth (fig. 10) also indicate nucleation around preexisting particles without spatial restrictions. Furthermore, the cauliflowerlike dolomite concretions in some fuller's earth resemble bulbous masses caused by algae communities described in the Persian Gulf sebkha by Illing, Wells, and Taylor (1965, p. 93).

### SOURCE MATERIALS

The problem of origin of palygorskite and sepiolite, inasmuch as they must have formed in place, is mainly the source of silica, aluminum, and magnesium which, together with water, are the chief components. Observations cited in the foregoing section indicate that dolomite has formed during or shortly after the evaporation of sea water; therefore, most of the magnesium required for the formation of palygorskite and sepiolite most likely came from the same source. The idea that these minerals can form by halmyrolysis or neoformation from sea water, if sufficient aluminum and silica are present, is supported by the findings of Wollast, Mackenzie, and Bricker (1968). They were able to synthesize a magnesian sepiolite at room temperature from sea water enriched with sodium metasilicate. Siffert and Wey (1962) also were able to make sepiolite at low temperatures in the laboratory from $Si(OH)_4$ and $MgCl_2$. Because most of the magnesium in palygorskite and sepiolite apparently came from sea water, the remaining problem is mainly concerned with the source of aluminum and silica. The abundant diatoms and silicoflagellate remains in deposits in the northern part of the district indicate that the water in which the fuller's earth accumulated was supplied with abundant silica. As sea water is ordinarily deficient in silica and aluminum, both probably were introduced in the form of silicate minerals and dissolved matter carried by streams draining areas of weathered rocks, rather than from volcanic ash. Reasons for these assumptions are given in the following paragraphs.

Probably some volcanic ash did accumulate in restricted basins in which palygorskite and sepiolite formed, but little support can be mustered for the idea that ash was the major parent material. Evidence has been found for the transport of very fine grained minerals for great distances by tropospheric air currents (Rex and others, 1969). Considering the volcanic activity in Southwestern United States, Mexico, and the Caribbean region, and in other parts of the world during Miocene time, it is unlikely that any appreciable thickness of Miocene sedimentary rocks anywhere is completely free of air-transported volcanic matter. However, only the following weak evidence and reasoning support the idea that the palygorskite and sepiolite in the Meigs-Attapulgus-Quincy district formed from volcanic ash: (1) Some deposits contain trace amounts of angular feldspar; (2) a few grains of embayed quartz of the type considered to be indicative of volcanic origin by Krynine (1946) occur in some places; (3) prolific expansion of diatom populations, as indicated by the abundance of these fossils in some deposits, has been attributed to the enrichment of sea water by volcanic ash (reviewed by Taliaferro, 1933, and Bramlette, 1946); and (4) opal or cristobalite in the fuller's earth and elsewhere in Miocene rocks is similar to material in other regions that has been considered as possibly originating from ash (Hathaway and others, 1970, p. E17; Heron and Johnson, 1966, p. 59-62). However, a nodule of amorphous silica from the fuller's earth investigated by scanning electron microscopy (Pollard and others, 1971) apparently formed from silica released by the dissolution of diatoms and not from ash.

As the foregoing paragraph states, volcanic ash was present in the parent materials of the fuller's earth, but evidence that the deposits formed primarily from this material is insufficient. No volcanic shards, the well-known criterion for recognizing bentonite, were found by the author during the examination of several thin sections and many powder mounts of the fuller's earth with a petrographic microscope. However, shards would be difficult to identify if present because many deposits contain isotropic shardlike fragments of diatoms which resemble volcanic shards. The diatom fragments, as noted by Grim (1970, p. 501), have been misinterpreted as being of volcanic origin; Espenshade and Spencer (1963, p. 20-21) also commented on the misidentification of shards.

The conclusion that the fuller's earth did not form primarily from ash is essentially the same as that reached by Kerr (1937, p. 548), who stated "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 fuller's 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." McClellan (1964, p. 98), after investigating the fuller's earth by X-ray and microscopic methods, also concluded that no support for the presence of large quantities of volcanic ash could be found. Furthermore, analyses of the major oxides (table 1) and minor elements (table 2) in the fuller's earth reveal no anomalous concentrations suggestive of volcanic origin, and no zeolite minerals have been found in the fuller's earth. Zeolite minerals, particularly clinoptilolite, in Miocene and other Tertiary beds in the Coastal Plain have been thought to be suggestive of volcanic-ash origin (Rooney and Kerr, 1967, p. 735; Heron and Johnson, 1966, p. 60-61; Reynolds, 1970, p. 834; Towe and Gibson, 1968).

As volcanic ash apparently was not the major parent material of the palygorskite, the most likely source of the silica and aluminum seems to be silicate minerals and dissolved matter carried in solution by streams. For several reasons, which have been summarized by Hathaway, McFarlin, and Ross (1970, p. E21), silica and aluminum transported from land areas would not be expected to enrich the water of the open ocean. However, conditions in the restricted environment in which the palygorskite and associated dolomite formed would be quite different from those in the open ocean. A chemical environment in which penecontemporaneous dolomite formed was probably also the type that would allow the concentration of introduced silica and aluminum.

The montmorillonite and kaolinite in the fuller's earth are among the silicate minerals most likely to have been introduced by streams, but montmorillonite may have formed in place by halmyrolysis, and both apparently have also formed from the weathering of palygorskite. Probably most of the montmorillonite that was intermixed with palygorskite and sepiolite either was deposited as such or formed penecontemporaneously with these clay minerals. However, much of the montmorillonite in the upper part of fuller's-earth deposits under thin overburden seems to have formed from weathering of palygorskite and sepiolite. This fact was as first recognized by Gremillion (1965b, p. 54-72). He proposed the following sequence of weathering: Palygorskite-montmorillonite-kaolinite. The evidence for this is that montmorillonite is far more abundant in the upper parts of deposits than in the lower part, and it tends to be much more abundant in deposits under light overburden than in deeply buried ones. Furthermore, the close association of palygorskite and montmorillonite in several different types of rocks in other regions indicates that these minerals are related in origin. Apparently either mineral can form from the other, if the required chemical environment exists. This conclusion is supported by the observations of Paquet and Millot (1972, p. 258-259), who summarized data which indicated that palygorskite is unstable in soils and commonly alters to montmorillonite. Kaolinite occurs mainly in the uppermost parts of deposits. In the northern part of the district, the uppermost parts of some deposits under thin porous overburden contain few clay minerals other than kaolinite. The formation of this kaolinite from montmorillonite is indicated by the gradation of the kaolinite-rich zones downward through zones in which these minerals are mixed and into zones containing mainly montmorillonite and little or no kaolinite. This evidence for the formation of kaolinite from montmorillonite is identical with that found by Altschuler, Dwornik, and Kramer (1963) in the Bone Valley and Citronelle Formations in central Florida.

#### DIAGENETIC CHANGES

Although most lithologic characteristics of the fuller's earth were formed soon after it was deposited or at least before it was deeply buried or weathered, some diagenetic changes have taken place. Probably most of the postburial changes in the fuller's earth were mainly minor transportation, compaction, and rearrangement of clay minerals, but some solution and precipitation of associated materials did take place. Evidence of such changes follows: (1) Pelecypod shells in one pit (table 3, sec. 1, bed 5) have been replaced by clay materials, indicating some postdepositional movement or generation of clay; (2) the fuller's earth in this same pit is cut by a vein filled with a breccia of the same material, which indicates movement into an open crack or joint, perhaps formed by collapse after solution of lower rocks; (3) diatoms, particularly in the southern part of the district, are poorly preserved and show evidence of ground-water solution; and (4) opal in concretions in one mine (p. 00) has been transported by ground water, inasmuch as it encloses clay and is clearly of postdepositional origin. Most of this silica apparently came from the dissolution of diatoms, but some may have been leached from other minerals in the zone of weathering, as has taken place farther south in Florida (Altschuler and others, 1963, p. 151).

#### RESOURCES

The only published estimate of resources of fuller's earth in the Meigs-Attapulgus-Quincy district was by Sellards and Gunter (1909, p. 285), who concluded that the total in Gadsden County, Fla., was 17.28 million tons. This estimate was based on the following very conservative assumptions: (1) An overburden thickness of 10 or 15 feet as the maximum limit of mineable deposits: (2) an average quantity of fuller's earth per acre of only 5,000 tons; and (3) only approximately 1 percent of Gadsden County underlain by fuller's earth.

Though much has been learned about the geology and distribution of fuller's earth since Sellards' and Gunter's estimate was made, any attempt to express the total amount of fuller's earth in the Meigs-Attapulgus-Quincy district must still be based on general information and geologic deductions. Thousands of exploratory holes have been drilled by companies in search for fuller's earth, but most of the information obtained by this drilling is of a proprietary nature and is not available for resource estimates.

Several factors having a bearing on the fuller's-earth resources make it certain that the total in the Meigs-Attapulgus-Quincy district is many times the original estimate by Sellards and Gunter. First, the original estimate was only for Gadsden County, Fla., and the district as defined in this report includes a larger area in Georgia. Second, the limit of strippable overburden has increased about six times because of the use of modern earth-moving equipment. Third, the extensive deposits of fuller's earth in the northern part of the district are as much as three times as thick as most deposits in Gadsden County.

### LIMESTONE AND DOLOMITE

Although limestone occurs at or near the surface at several localities in the Meigs-Attapulgus-Quincy district, little use has been made of it, and no quarries are active in the district at present. Most crushed limestone for road-metal, concrete, and agricultural lime is trucked from active quarries a few miles beyond the limits of the district. One of these quarries is operated by the Bridgeboro Lime and Stone Co. near Bridgeboro, Ga. (Furcron and Fortson, 1960, p. 9). This quarry is approximately 20 miles north of the northern boundary of the district. Two quarries are operated primarily for agricultural lime west of the district by the Dixie Lime and Stone Co. One quarry is in limestone of Eocene age and is approximately 3 miles northwest of Marianna, Fla. The second one is in dolomitic rock and is north of Sink Creek, Fla., in an area mapped by Moore (1955, pl. 1) as underlain by Suwannee Limestone.

Use of limestone in the district has been limited; small quantities were dug many years ago to make natural hydraulic cement, mortar, and building stone. The cement was produced in a small plant which operated for a year or two at River Junction, on the south side of Chattahoochee, Fla. (Cummings, 1899; Mossom, 1925, p. 136). It was used principally in bonding white sand brick from which some of the older buildings in northern Florida are constructed. The site of the quarry where the raw material for this cement was dug was not found, but the material used was probably a fine-grained argillaceous dolomitic rock in the Tampa Formation, which is exposed near River Junction. A small quantity of dolomitic limestone was quarried east of Chattahoochee, Fla., for a local dam embankment (Mossom, 1925, p. 136). Lime for mortar and other uses was once burned in a small kiln 5 miles east of Thomasville, Ga. (Brantly, 1916, p. 192). Apparently this kiln closed shortly after the railroads were constructed in south Georgia. Building stone, most of which was known as "chimney stone," was dug at several places in the district (Brantly, 1916, p. 182) and used mainly in constructing farm buildings. Minor quantities of soft sandy and clayey calcareous material, which Hendry and Sproul (1966, p. 101, 104) classified as marl, have been dug in southwestern Leon County, Fla., and used locally as a stabilizer on rural roads. This material, however, cannot properly be called a limestone.

Most outcrops of limestone occur in the western part of the district, but a few are scattered throughout the eastern part. Those in the western part are chiefly in sinkholes and stream channels along the foot of the solution escarpment in Georgia and in stream channels and cutbanks on the east side of the Apalachicola valley in Florida. The deposits in the eastern part of the district occur in scattered open or partly filled sinkholes. Most outcrops of dolomitic rock in the Meigs-Attapulgus-Quincy district are in the vicinity of Chattahoochee, Fla. Thin dolomitic beds are exposed in the valley of Mosquito Creek east of the State Hospital, in borrow pits east of the Apalachicola River, and near the railroad station at River Junction on the south side of Chattahoochee.

Resources of limestone and dolomitic rock within the Meigs-Attapulgus-Quincy district are large, and deposits suitable for agricultural lime could be quarried at several places. Some of the limestone is of high purity, and some of sufficient hardness for use as road metal probably can be found in the district. However, most of the limestone and dolomite is in thin impure beds which are unfavorable for large-scale quarrying, and most of the carbonate rock is too soft to be used for road metal. Locations of limestone outcrops and chemical analyses of samples from several places in the Georgia part of the district were given by Furcron and Fortson (1960) and by Brantley (1916, p. 173-200). Hendry and Yon (1958, p. 47-50) listed the locations of most of the limestone and dolomite outcrops in the Florida part of the district.

## PHOSPHATE

Phosphate was discovered on the Toy property 3 miles west of Boston, Ga., in 1889 (McCallie, 1896, p. 61), and shortly thereafter small deposits were found at other localities east of Thomasville, Ga. An attempt was made to mine and process the phosphate on the Toy property, but only one or two carloads were shipped, and the operation was shut down less than 3 years after the discovery. McCallie (1896, p. 61) concluded that the lack of success was because of the "limited quantity of phosphate and great thickness of overburden." These one or two carloads have been the only phosphate mined in Georgia, and no phosphate has been mined in the Florida part of the Meigs-Attapulgus-Quincy district.

The phosphate deposits on the Toy property are in the Hawthorn Formation, but they are so poorly exposed that little can be observed at the sites, and the stratigraphic position in the formation could not be determined. The deposits were described by McCallie (1896, p. 61) as occuring in nodules and concretions ranging from less than 1 inch to more than 1 foot in longest dimension. The phosphate masses are scattered throughout reddish sandy clays overlying the irregular upper surface of limestone. Both soft and hardrock types of phosphate were present in the material mined.

In addition to the small occurrences of phosphate described above, phosphate-bearing minerals have been noted at several places in the Meigs-Attapulgus-Quincy district. Trace amounts of small phosphate pellets and phosphatic bone and teeth remains, consisting of carbonate-fluorapatite, $Ca_5(PO_4)_3F$, were recognized in sandy and clayey cuttings from many wells in both the Georgia and Florida parts of the district. These phosphatic materials are most commonly observed in cuttings from the Hawthorn Formation, but they also occur in the Tampa Limestone. Phosphatic materials are concentrated locally, but no deposits of sufficient size and grade found in the district were considered suitable for mining. One such submarginal deposit in the Hawthorn Formation was penetrated in an exploration hole drilled 2 miles south of Thomasville, Ga., by the Engineering Experiment Station (Georgia Inst. Technology and Georgia Dept. Mines, Mining and

Geology, 1969, p. 140-145). The rock penetrated by this hole at depths of 39 to 49 feet was 13.15 percent BPL (bone phosphate of lime).

Most phosphate in pellets and skeletal remains can be considered primary phosphate composed of fluorapatite, as it is probably in the form in which it was originally deposited, but several types of secondary phosphate also occur in the district. Much of the secondary phosphate apparently has been dissolved from primary material and transported by ground water. The mineral wavellite, $Al_3(PO_4)_2(OH)_3 \cdot 5H_2O$, was found in several forms. One type in the Hawthorn Formation at several localities is dense-gray material in boxwork accumulations in clay beds; it has apparently formed in dessication cracks or open joints. This mineral was also found in ovoid concretions having an appearance similar to chert. Wavellite in in the Miccosukee Formation at one locality (table 3, sec. 5, bed 7) is in the form of rounded concretions ranging from one-half inch to 2 inches in diameter that locally coalesce into irregular beds. Francolite, $Ca_{10}(PO_4\text{-}CO_3)F_{2\text{-}3}OH_{2\text{-}3}$, was found in white masses appearing similar to kaolin in one well drilled by the Florida Bureau of Geology in Gadsden County, Fla. (table 5, W7539).

### RAW MATERIAL FOR COMMON BRICK

Common brick was, no doubt, made at an early date from local clayey materials and soils on several of the larger farms and plantations in the district, but the first large use of local materials in making brick apparently was in the construction of the United States arsenal, which operated at Chattahoochee, Fla., from 1832 to 1861. A historical marker at the State Hospital now occupying the arsenal site states that the original construction was of brick burned from local clays. The source of these materials was not found, but there is little possibility that they could have been other than very sandy clays in the Hawthorn Formation or silty alluvium in the valley of the Apalachicola River or one of its tributaries.

Two small common-brick plants are now operating in the Meigs-Attapulgus-Quincy district, and three others have been dismantled. The active ones are the Arnold Brick Co. at Thomasville, Ga., and the one operated by the Apalachee Correctional Institution at Chattahoochee, Fla. The Arnold plant produces mainly red and dark-reddish-brown brick for the local market. Similar bricks are made at the Chattahoochee plant, which has a capacity of approximately 250,000 bricks a month. The entire output of this plant is used in construction by the State of Florida and its political subdivisions. Two of the now-dismantled plants were in eastern Gadsden County, Fla. (Sellards and Gunter, 1918, p. 17). One of them, the Ocklockonee Brick Co., was on the Seaboard Air Line Railway about 1 mile west of the Ochlockonee River; the second, the Tallahassee Pressed Brick Co. was on the Seaboard Air Line Railway a short distance west of the same river. The third plant was at Bainbridge, Ga. (Smith, 1931, p. 329).

The raw material used for brick by the plant at Chattahoochee, Fla., is clayey silt rich in organic matter, dug from alluvium along the Apalochicola River. The raw material formerly used by the two dismantled plants in Florida was similar alluvium in terrace deposits west of the Ochlockonee River; the inactive plant near Bainbridge, Ga., used alluvium clay along the Flint River. None of these materials can be considered of high quality for making brick; they have been used because suitable high-grade clays have not been found in the region. The materials used do not contain sufficient clay minerals to be properly called clays in a mineralogical sense, but they are classed as miscellaneous clays in production statistics, because all materials used in making common brick are referred to in this way. Resources of raw materials of this type in the region are virtually inexhaustible. Furthermore, the sediment accumulating in the Jim Woodruff Reservoir is probably similar in mineral composition to the alluvium used by the plant at Chattahoochee, and if this sediment is ever dredged for brick material or other useful purposes, it would, in effect, be a replaceable resource.

The raw material used by the plant at Thomasville, Ga., is weathered clayey sand interbedded with sandy clay, forming part of the Miccosukee Formation. This material, though it has been used for brick for many years, cannot be considered a high-grade brick clay. Test pieces made from the purer clays in it checked when fired (Smith, 1931, p. 328). The high sand content of this material probably reduces shrinkage and allows the material to be used to make bricks. Similar earthy materials occur at many places in the Meigs-Attapulgus-Quincy district, but only the surficial materials are likely to be suitable for use in brick. West and north of Tallahassee, samples of purer but less weathered clays, which are thereore probably rich in montmorillonite, had poor firing characteristics when tested (Hendry and Sproul, 1966, table 6). Though very large quantities of both weathered and comparatively fresh sandy clays and clayey sand occur in the Miccosukee Formation, uniform deposits suitable for the raw material for a large modern brick plant probably do not exist in this formation within the district.

### SILICA AND CONSTRUCTION SAND

Silica sand is produced by one company, and sand used in construction is dug or dredged at several places in the Meigs-Attapulgus-Quincy district. The silica sand is produced by the Dawes Silica Mining Co., operating a plant at the Dawesville siding of the Atlantic Coast Line Railroad 5 miles southeast of Ochlocknee, Ga. The sand is washed, the heavy minerals are separated, and the sand is screened to size grades. It is sold for making glass, foundry molds, concrete, masonry mortar, abrasives, and filters, and a less than 150-mesh grade is used as silica flour. The sand is dug from river-terrace deposits that occur in lenticular units. Some lenses are coarse grained and contain minor quanitites of gravel, and others are mainly medium and fine grained and contain minor quantities of silt. The wide range in grain size permits the production of the didferent grades.

Several grades of sand used mainly in concrete, mortar, plaster, and drainage fields are produced by the Roberts and the Johnson Sand Companies south of Florida Highway 20, approximately 7 miles west of Tallahassee, Fla. Naturally washed sand has been excavated intermittently from the bed, and less pure sand has been dug from the banks of the Ochlockonee River in Leon County, Fla. (Hendry and Sproul, 1966, p. 101). Sand is also excavated from this river east of Gibson, a small town on the Seaboard Air Line Railway in eastern Gadsden County, Fla. This sand is used for miscellaneous construction purposes and for making white cement-bonded brick in a plant at Gibson. Sand used in concrete products and for several construction purposes is dug from alluvial deposits north of West Bainbridge, Ga. Both sand and gravel are dredged from the Apalochicola River by the Florida Gravel Co. at Chattahoochee, Fla. Impure sand, mainly in the Miccosukee Formation, is dug for local use at many pits scattered throughout the district.

## REFERENCES CITED


Altschuler, Z. S., Clarke, R. S., Jr., and Young, E. J., 1958, Geochemistry of uranium in apatite and phosphorite: U.S. Geol. Survey Prof. Paper 314-D, p. 45-90.

Altschuler, Z. S., Dwornik, E. J., and Kramer, Henry, 1963, Transformation of montmorillonite to kaolinite during weathering: Science, v. 141, no. 3576, p. 148-152.

Bailey, S. W., 1972, Recent advancements in the crystal structures and crystal chemistry of layer silicates: Assoc. Internat. Étude Argiles [A.I.P.E.A.] Conf., Madrid, June 25-30, Preprints, v. 1, p. 3-13.

Bay, H. X., and Munyan, A. C., 1935, The bleaching clays of Georgia: Georgia Geol. Survey Inf. Circ. 6, 4 p.

———1940a, The bleaching clays of Georgia: U.S. Geol. Survey Bull. 901, p. 251-300.

———1940b, Preliminary investigation of Florida bleaching clays: U.S. Geol. Survey Bull. 901, p. 301-333.

Bradley, W. F., 1940, The structural scheme of attapulgite: Am. Mineralogist, v. 25, no. 6, p. 405-410.

Bramlette, M. N., 1946, The Monterey Formation of California and the origin of its siliceous rocks: U.S. Geol. Survey Prof. Paper 212, 57 p.

Brantly, J. E., 1916, A report on the limestones and marls of the Coastal Plain of Georgia: Georgia Geol. Survey Bull. 21, 300 p.

Buie, B. F., and Gremillion, L. R., 1963, Attapulgite in fuller's earth deposits of Georgia and Florida: Georgia Mineral Newsletter, v. 16, no. 1-2, p. 20-25.

Caillère, Simonne, 1951, Sur la présence d'une palygorskite à Tafraout (Maroc): Acad. Sci. Paris, Comptes rendus, v. 233, no. 13, p. 697-698.

Caillère, Simonne, and Rouaix, Serge, 1958, Sur la présence de palygorskite dans la région de Taguenout-Hagueret (A.O.F.): Acad. Sci. Paris, Comptes rendus, v. 246, no. 9, p. 1442-1444.

Calver, J. L., 1957, Mining and mineral resources: Florida Geol. Survey Bull. 39, 132 p.

Capdecomme, Laurent, and Kulbicki, G., 1954, Argiles des gîtes phosphatés de la région de Thiès (Senegal): Soc. Française Minéralogie et Cristallographie Bull., v. 77, no. 1-3, p. 500-514.

Cathcart, J. B., 1963a, Economic geology of the Keysville quadrangle, Florida: U.S. Geol. Survey Bull. 1128, 82 p.

———1963b, Economic geology of the Plant City quadrangle, Florida: U.S. Geol. Survey Bull. 1142-D, 56 p.

Christ, C. L., Hathaway, J. C., Hostetler, P. B., and Shepard, A. O., 1969, Palygorskite—New X-ray data: Am. Mineralogist, v. 54, nos. 1-2, p. 198-205.

Clays and Clay Minerals, 1971, Summary of national and international recommendations on clay mineral nomenclature, 1969-70 CMS Nomenclature Committee: Clays and Clay Minerals, v. 19, p. 129-132.

Cole, W. S., 1944, Stratigraphic and paleontologic studies of wells in Florida—No. 3: Florida Geol. Survey Bull. 26, 168 p.

Cook, G. H., and Smock, J. C., 1878, Report on the clay deposits of Woodbridge, South Amboy, and other places in New Jersey: Trenton, N.J., New Jersey Geol. Survey, 381 p.

Cooke, C. W., 1925, The Coastal Plain, *in* La Forge, Laurence, Cooke, C. W., Keith, Arthur, and Campbell, M. R., Physical geography of Georgia: Georgia Geol. Survey Bull. 42, p. 19-54.

———1939, Scenery of Florida interpreted by a geologist: Florida Geol. Survey Bull. 17, 118 p.

———1943, Geology of the Coastal Plain of Georgia: U.S. Geol. Survey Bull. 941, 121 p.

Cooke, C. W., and Mansfield, W. C., 1936, Suwannee Limestone of Florida [abs.]: Geol. Soc. America, Proc. 1935, p. 71-72.

Cooke, C. W., and Mossom, D. S., 1929, Geology of Florida: Florida Geol. Survey 20th Ann. Rept., p. 29-227.

Cummings, Uriah, 1899, American rock cement: U.S. Geol. Survey Ann. Rept. 20, 1898-99, (cont.), p. 547-550.

Dall, W. H., and Harris, G. D., 1892, Correlation papers; Neocene: U.S. Geol. Survey Bull. 84, 349 p.

Espenshade, G. H., and Spencer, C. W., 1963, Geology of the phosphate deposits of northern peninsular Florida: U.S. Geol. Survey Bull. 1118, 115 p.

Fenneman, N. M., 1938, Physiography of eastern United States: New York, McGraw-Hill Book Co., 714 p.

Fleischer, Peter, 1972, Sepiolite associated with Miocene diatomite. Santa Cruz Basin, California: Am Mineralogist, v. 57, nos. 5-6, p. 903-913.

Furcron, A. S., and Fortson, C. W., Jr., 1960, Commercial limestones of the Flint River basin south of Albany, Georgia: Georgia Mineral Newsletter, v. 13, no. 2, p. 45-57.

Gardner, Julia, 1926, The molluscan fauna of the Alum Bluff Group of Florida, Part I. Prionodesmacea and Anomalodesmacea: U.S. Geol. Survey Prof. Paper 142-A, 79 p.

Georgia Institute of Technology and Georgia Department of Mines, Mining and Geology, 1969, South Georgia Minerals Program, Project Report 11: Atlanta, Ga., Georgia Inst. Technology, 165 p.

Greaves-Walker, A. F., Bugg, S. L., Hagerman, R. S., 1951, The development of lightweight aggregate from Florida clays: Florida Eng. and Indus. Exp. Sta. Bull. Ser. 46 (Eng. Progress at Univ. Florida, v. 5, no. 9), 23 p.

Gremillion, L. R., 1965a, Miocene near-shore deposits of attapulgite: Coastal Research Notes, no. 11, p. 11-12.

———1965b, The origin of attapulgite in the Miocene strata of Florida and Georgia: Tallahassee, Florida State Univ. Ph.D. thesis, 159 p.

Grim, R. E., 1933, Petrography of the fuller's earth deposits, Olmstead, Ill., with a brief study of some non-Illinois earths: Econ. Geology, v. 28, no. 4, p. 344-363.

———1962, Applied clay mineralogy: New York, McGraw-Hill, Book Co., 422 p.
———1968, Clay mineralogy [2d ed.]: New York, McGraw-Hill Book Co., 596 p.
———1970, The texture and composition of bentonites: Israel Jour. Chemistry, v. 8, p. 501-503.
Haas, C. Y., 1970, Attapulgite clays for future industrial mineral markets [abs.]: Mining Eng. v. 22, no. 12, p. 63.
———1971, Attapulgite clays for future industrial mineral markets: Am. Inst. Mining, Metall. and Petroleum Engineers, Soc. Mining Engineers, Centennial Ann. Mtg. New York, N.Y., Feb. 26-Mar. 4, 1971, preprint 71-H-54, 13 p.
Haden, W. L., Jr., 1963, Attapulgite—Properties and uses, *in* Swineford, Ada, ed., Clays and clay minerals—Proceedings of the Tenth National Conference on Clays and Clay Minerals, Austin, Tex., Oct. 14-18, 1961: New York, Macmillan Co., p. 284-290.
Haden, W. L., Jr., and Schwint, I. A., 1967, Attapulgite—Its properties and applications: Indus. and Eng. Chemistry, v. 59, no. 9, p. 58-69.
Hagner, A. F., 1939, Adsorptive clays of the Texas Gulf Coast: Am. Mineralogist, v. 24, no. 2, p. 67-108.
Hathaway, J. C., McFarlin, P. F., and Ross, D. A., 1970, Mineralogy and origin of sediments from drill holes on the continental margin off Florida: U.S. Geol. Survey Prof. Paper 581-E, 26 p.
Hathaway, J. C., and Sachs, P. L., 1965, Sepiolite and clinoptilolite from the Mid-Atlantic Ridge: Am. Mineralogist, v. 50, nos. 7-8, p. 852-867.
Hendry, C. W., Jr., and Sproul, C. R., 1966, Geology and ground-water resources of Leon County, Florida: Florida Geol. Survey Bull. 47, 178 p.
Hendry, C. W., Jr., and Yon, J. W., Jr., 1958, Geology of the area in and around the Jim Woodruff reservoir: Florida Geol. Survey Rept. Inv. 16, pt. 1, 52 p.
———1967, Stratigraphy of upper Miocene Miccosukee Formation, Leon and Jefferson Counties, Florida: Am. Assoc. Petroleum Geologists Bull., v. 51, no. 2, p. 250-256.
Heron, S. D., Jr., and Johnson, H. S., Jr., 1966, Clay mineralogy, stratigraphy, and structural setting of the Hawthorn Formation, Coosawhatchie district, South Carolina: Southeastern Geology, v. 7, no. 2, p. 51-63, 1 fig.
Herrick, S. M., and LeGrand, H. E., 1964, Solution subsidence of a limestone terrane in southwest Georgia: Internat. Assoc. Sci. Hydrology Bull., v. 9, no. 2, p. 25-36.
Herrick, S. M., and Vorhis, R. C., 1963, Subsurface geology of the Georgia Coastal Plain: Georgia Geol. Survey Inf. Circ. 25, 78 p.
Hester, N. C., and Pryor, W. A., 1972, Blade-shaped crustacean burrows of Eocene age—A composite form of *Ophiomorpha:* Geol. Soc. America Bull., v. 83, no. 3, p. 677-688.
Heystek, Hendrik, and Schmidt, E. R, 1953, The mineralogy of the attapulgite-montmorillonite deposits in the Springbok Flats, Transvaal: Geol. Soc. South Africa Trans., v. 56, p. 99-119.
Huggins, C. W., Denny, M. V., and Shell, H. R., 1962, Properties of palygorskite, an asbestiform mineral: U.S. Bur. Mines Rept. Inv. 6071, 17 p.
Illing, L. V., Wells, A. J., and Taylor, J. C. M., 1965, Penecontemporary dolomite in the Persian Gulf, *in* Pray, L. C., and Murray, R. C., eds., Dolomitization and limestone diagenesis—A symposium: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 13, p. 89-111.
International Clay Conference, 1972, Field trip guide: Assoc. Internat. Étude Argiles [A.I.P.E.A.] Conf. Madrid, June 25-30, p. 2-1 to 2-10.
Johnson, L. C., 1892, The Chattahoochee embayment: Geol. Soc. America Bull., v. 3, p. 128-132.
Keller, W. D., 1970, Environmental aspects of clay minerals: Jour. Sed. Petrology, v. 40, p. 788-813.
Keroher, G. C., and others, 1966, Lexicon of geologic names of the United States for 1936-1960; Part 1, A-F: U.S. Geol. Survey Bull. 1200, 1448 p.
Kerr, P. F., 1937, Attapulgus clay: Am. Mineralogist, v. 22, no. 5, p. 534-550.
Kerr, P. F., and others, 1950, Analytical data on reference clay materials: Am. Petroleum Inst. Proj. 49, Clay mineral standards, Prelim. Rept. 7, 160 p.
Krynine, P. D., 1946, Microscopic morphology of quartz types, *in* Geologia, paleontologia, mineralogia e petrologia, 2a Com.: Cong. Panam. Engenharia Minas e Geologia, 2d. Rio de Janeiro, 1946, Anais, v. 3, p. 35-49.
Lapparent, Jacques de, 1935, Sur un constituant essentiel des terres à foulon: Acad. Sci. Paris, Comptes rendus, v. 201, p. 481-483.
———1936, Formule et schema structural de l'attapulgite: Acad. Sci. Paris, Comptes rendus, v. 202, p. 1728-1731.
Longchambon, Henri, 1935, Sur les constituants minéralogiques essentiels des argiles, en particulier des terres à foulon: Acad. Sci. Paris, Comptes rendus, v. 201, no. 10, p. 483-485.
Loughnan, F. C., 1960, Further remarks on the occurrence of palygorskite at Redbank Plains, Queensland: Royal Soc. Queensland Proc., v. 71, p. 43-50.
Lucas, Jacques, 1968, The transformation of clay minerals during sedimentation; a study on Triassic clays: Jerusalem, Israel Programs Sci. Translations, 203 p. (Originally published in French as Service Carte Géol. Alsace et Lorraine Mém. 24).
McCallie, S. W., 1896, A preliminary report on a part of the phosphates and marls of Georgia: Georgia Geol. Survey Bull. 5-A, 101 p.
McClellan, G. H., 1964, Petrology of attapulgus clay in north Florida and southwest Georgia: Urbana, Ill., Univ. Illinois Ph.D. thesis, 119 p.
MacNeil, F. S., 1947, Geologic map of the Tertiary and Quaternary formations of Georgia: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 72.
Martin Vivaldi, J. L., and Robertson, R. H. S., 1971, Palygorskite and sepiolite (the hormites), *in* Gard, J. A., ed., The electron-optical investigation of clays: Mineralog. Soc. London Mon. 31, p. 255-275.
Millot, Georges, 1962, Crystalline neoformations of clays and silica, *in* Physical sciences; some recent advances in France and the United States (Symposium, New York Univ. 1960): New York, New York Univ. Press, p. 180-191.
———1967, Signficiation des études récentes sur les roches argileuses dans l'interprétation des faciès sédimentaires (y compris les séries rouges): Sedimentology, v. 8, no. 4, p. 259-280.
Millot, Georges, Lucas, Jacques, and Wey, Raymond, 1963, Research on evolution of clay minerals and argillaceous and siliceous neoformation, *in* Swineford, Ada, ed., Clays and clay minerals—Proceedings of the Tenth National Conference on Clays and Clay Minerals, Austin, Tex., Oct. 14-18, 1961: New York, Macmillan Co., p. 399-412.
Millot, Georges, Radier, Henri, and Bonifas, Marthe, 1957, La sédimentation argileuse à attapulgite et montmorillonite: Soc. Géol. France Bull., ser. 6, v. 7, no. 4-5, p. 425-433.
Miser, H. D., 1913, Developed deposits of fuller's earth in Arkansas: U.S. Geol. Survey Bull. 530, p. 207-220.
Moore, W. E., 1955, Geology of Jackson County, Florida: Florida Geol. Survey Bull. 37, 101 p.
Mossom, Stuart, 1925, A preliminary report on the limestone and marls of Florida: Florida State Geol. Survey 16th Ann. Rept., 1923-24, p. 27-203.
Munsell Color Co., 1954, Munsell soil color chart: Baltimore, Md., Munsell Color Co.
Nutting, P. G., 1943, Adsorbent clays, their distribution, properties, production, and uses: U.S. Geol. Survey Bull. 928-C, p. 127-219.
Olson, N. K., compiler and editor, 1966, Geology of the Miocene and Pliocene series in the north Florida-south Georgia area: Atlantic

Coastal Plain Geol. Assoc. (7th Ann. Field Conf.) and Southeastern Geol. Soc. (12th Ann. Field Conf.), 94 p.
Oulton, T. D., 1965, Mining, production, and uses of attapulgite clay products: Am. Inst. Mining, Metall., and Petroleum Engineers, Soc. Mining Engineers, Preprint 65H39, 10 p.
Ovcharenko, F. D., Nichiporenko, S. P., Kruglitskii, and Tretinnik, V. Yu., 1967, Investigation of the physiochemical mechanics of clay-mineral dispersions. Translated from Russian by Z. Lerman: Jerusalem, Israel Program Sci. Translations, 146 p.
Owen, Vaux, Jr., 1963, Geology and ground-water resources of Mitchell County, Georgia: Georgia Geol. Survey Inf. Circ. 24, 40 p.
Paquet, Hélène, and Millot, Georges, 1972, Geochemical evolution of clay minerals in the weathered products and soils of Mediterranean climates: Assoc. Internat. Étude Argiles [A.I.P.E.A.]Conf., Madrid, June 25-30, Preprints, v. 1, p. 255-261.
Patterson, S. H., and Herrick, S. M., 1971, Chattahoochee anticline, Apalachicola embayment, and Gulf trough and related structural features, southwestern Georgia—fact or fiction: Georgia Dept. Mines, Mining, and Geology Inf. Circ. 41, 16 p.
Peterson, M. N. A., Edgar, N. T., von der Borch, C. C., and Rex, R. W., 1970, Cruise leg summary and discussion, chap. 20 *in* Initial reports of the Deep Sea Drilling Project—V. 2, Leg 2 of cruises of *Glomar Challenger*, Hoboken, N.J., to Dakar, Senegal, Oct.-Nov. 1968: Washington D.C., U.S. Govt. Printing Office, p. 413-427.
Pollard, C. O., Jr., Weaver, C. E., and Beck, K. C., 1971, Anatomy of a silica nodule [abs.]: Geol. Soc. America Abs. with Programs, v. 3, no. 5, p. 340-341
Pressler, E. D., 1947, Geology and occurrence of oil in Florida: Am. Assoc. Petroleum Geologists Bull., v. 31, no. 10, p. 1851-1862.
Puri, H. S., 1953, Contributions to the study of the Miocene of the Florida panhandle: Florida Geol. Survey Bull. 36, 345 p.
Puri, H. S., and Vernon, R. O., 1964, Summary of the geology of Florida and a guidebook to the classic exposures: Florida Geol. Survey Spec. Pub. 5, 312 p.
Rainwater, E. H., 1956, Geology of Jackson County, Florida, by Wayne E. Moore [a review]: Am. Assoc. Petroleum Geologists Bull., v. 40, no. 7, p. 1727-1729.
Rateev, M. A., 1965, Modification degree of clay minerals during the stage of sedimentation and diagenesis of marine deposits, *in* Rosenquist, I. Th., and Graff-Petersen, P., eds., Internat. Clay Conf., Stockholm 1963, Proc., v. 2 : New York, Macmillan Co., p. 171-180.
Rex, R. W., 1970, X-ray mineralogy studies, chap. 11 *in* Initial reports of the Deep Sea Drilling Project—V. 2, Leg 2 of cruises of *Glomar Challenger*, Hoboken, N.J., to Dakar, Senegal, Oct.-Nov. 1968: Washington, D.C., U.S. Govt. Printing Office, p. 329-346.
Rex, R. W., Syers, J. K., Jackson, M. L., and Clayton, R. N., 1969, Eolian origin of quartz in soils of Hawaiian Islands and in Pacific pelagic sediments: Science, v. 163, no. 3864, p. 277-279.
Reynolds, W. R., 1970, Mineralogy and stratigraphy of lower Tertiary clays and claystones of Alabama, *in* Symposium on environmental aspects of clay minerals: Jour. Sed. Petrology, v. 40, no. 3, p. 829-838.
Rich, A. D., 1960, Bleaching clay, *in* Gillson, J. L., and others, eds., Industrial minerals and rocks—nonmetallics other than fuels [3d ed.]: New York, Am Inst. Mining, Metall., and Petroleum Engineers, p. 93-101.
Rooney, T. P., and Kerr, P. F., 1967, Mineralogic nature and origin of phosphorite, Beaufort County, North Carolina: Geol. Soc. America Bull., v. 78, no. 6, p. 731-748.
Ross, C. S., and Hendricks, S. B., 1945, Minerals of the montmorillonite group, their origin and relation to soils and clays: U.S. Geol. Survey Prof. Paper 205-B, p. 23-79 [1946].
Ross, C. S., and Shannon, E. V., 1926, The minerals of bentonite and related clays and their physical properties: Am. Ceramic Soc. Jour., v. 9, no. 2, p. 77-96.
Sellards, E. H., 1908, Mineral industries: Florida Geol. Survey Ann. Rept. 1, p. 26-53.
______1910, The fuller's earth deposits of Florida: Mineral Industry, 1909, v. 18, p. 267-270.
______1914a, Mineral industries and resources of Florida: Florida Geol. Survey Ann. Rept. 6, p. 21-114.
______1914b, Some Florida lakes and lake basins: Florida Geol. Survey Ann. Rept. 6, p. 115-159.
Sellards, E. H., and Gunter, Herman, 1909, The fuller's earth deposits of Gadsden County, Fla., with notes on similar deposits found elsewhere in the State: Florida Geol. Survey Ann. Rept. 2, 1908-09, p. 253-291.
______1918, Geology between the Apalachicola and Ochlockonee Rivers in Florida: Florida Geol. Survey Ann. Repts. 10-11, p. 9-56.
Sever, C. W., 1962, Geologic, hydrologic, physiographic, and geophysical data indicating a regional structure transecting the Coastal Plain of Georgia [abs.]: Geol. Soc. America, Southeastern Sec., Ann. Mts., Atlanta, April 1962, Program, p. 16.
____1964, Relation of economic deposits of attapulgite and fuller's earth to geologic structure in southwestern Georgia: U.S. Geol. Survey Prof. Paper 501-B, p. B116-B118.
______1966a, Miocene structural movements in Thomas County, Georgia: U.S. Geol. Survey Prof. Paper 550-C, p. C12-C16.
______1966b, Reconnaissance of the ground water and geology of Thomas County, Georgia: Georgia Geol. Survey Inf. Circ. 34, 14 p.
Sever, C. W., and Herrick, S. M., 1967, Tertiary stratigraphy and geohydrology in southwestern Georgia: U.S. Geol. Survey Prof. Paper 575-B, p. B50-B53.
Shapiro, Leonard, and Brannock, W. W., 1956, Rapid analysis of silicate rocks: U.S. Geol. Survey Bull. 1036-C, p. 19-56.
Shearer, H. K., 1917, A report on the bauxite and fuller's earth of the Coastal Plain of Georgia: Georgia Geol. Survey Bull. 31, 340 p.
Shinn, E. A., Ginsburg, R. N., Lloyd, R. M., 1965, Recent supratidal dolomite from Andros Island, Bahamas, *in* Pray, L. C., and Murray, R. C., eds., Dolomitization and limestone diagenesis—A symposium: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 13, p. 112-123.
Shrum, R. A. [1970], Distribution of kaolin and fuller's earth mines and plants in Georgia and north Florida: Georgia Dept. Mines, Mining, and Geology, map.
Siddiqui, M. K. H., 1968, Bleaching earths: New York, Pergamon Press, 86 p.
Siffert, Bernard, and Wey, Raymond, 1962, Synthèse d'une sépiolite à température ordinaire: Acad. Sci. Paris, Comptes rendus, v. 254, no. 8, p. 1460-1462.
Silliman, Benjamin, 1820, Sketches of a tour in the counties of New-Haven and Litchfield in Connecticut, with notices of the geology, mineralogy, and scenery, etc.: Am. Jour. Sci., v. 2, no. 2, p. 201-235.
Slansky, Maurice, Camez, Thérèse, and Millot, Georges, 1959, Sédimentation argileuse et phosphatee au Dahomey: Soc. Geol. France Bull., ser. 7, v. 1, no. 2, p. 150-155.
Smith, R. W., 1931, Shales and brick clays of Georgia: Georgia Geol. Survey Bull. 45, 348 p.
Spencer, J. W. W., 1891, First report of progress 1890-91: Georgia Geol. Survey, 128 p.
Stephen, Isaac, 1954, An occurrence of palygorskite in the Shetland isles: Mineral Mag., v, 30, no. 226, p. 471-480.
Taliaferro, N. L., 1933, The relation of volcanism to diatomaceous and associated siliceous sediment: California Univ. Dept. Geol. Sci. Bull., v. 23, no. 1, p. 1-56.
Tanner, W. F., 1966, Late Cenozoic history and coastal morphology of the Apalachicola River region, western Florida, *in* Shirley, M. L., and Ragsdale, J. A., eds., Deltas in their geologic framework: Houston, Tex., Houston Geol. Soc., p. 83-97.
Toulmin, L. D., Jr., 1952, Sedimentary volumes in Gulf Coastal Plain

of the United States and Mexico; Part 2, Volume of Cenozoic sediments in Florida and Georgia: Geol. Soc. America Bull., v. 63, no. 12, pt. 1, p. 1165-1176.

Toulmin, L. D., Jr., and LaMoreaux, P. E., 1963, Stratigraphy along Chattahoochee River, connecting link between Atlantic and Gulf Coastal Plains: Am. Assoc. Petroleum Geologists Bull., v. 47, no. 3, p. 385-404.

Toulmin, L. D., Jr., and Winters, S. S., 1954, Pre-Eocene solution features in southeast Alabama and southwest Georgia: Florida State Univ. Studies, no. 13, p. 72-83.

Towe, K. M., and Gibson, T. G., 1968, Stratigraphic evidence for widespread late early Eocene volcanism, eastern North America: Geol. Soc. America Ann. Mtg., Mexico City, Mexico, 1968, Program with Abstracts, p. 299-300.

Uchupi, Elazar, 1966, Map showing relation of land and submarine topography, De Soto Canyon to Great Bahama Bank: U.S. Geol. Survey Misc. Geol. Inv. Map I-475.

Vaughan, T. W., 1902, Fuller's earth of southwestern Georgia and western Florida: U.S. Geol. Survey, Mineral Resources of the United States, Calendar Year 1901, p. 922-934.

——1903, Fuller's earth deposits of Florida and Georgia: U.S. Geol. Survey Bull. 213, p. 392-399.

Veatch, J. O., and Stephenson, L. W., 1911, Preliminary report on the geology of the Coastal Plain of Georgia: Georgia Geol. Survey Bull. 26, 466 p.

Vernon, R. O., 1951, Geology of Citrus and Levy Counties, Florida: Florida Geol. Survey Bull. 33, 256 p.

von der Borch, C. C., Rubin, Meyer, and Skinner, B. J., 1964, Modern dolomite from South Australia: Am. Jour. Sci., v. 262, no. 9, p. 1116-1118.

Weaver, C. E., 1968, Mineral facies in the Tertiary of the continental shelf and Blake Plateau: Southeastern Geology, v. 9, no. 2, p. 57-63.

Weaver, C. E., and Beck, K. C., 1972, Vertical variability in the attapulgite mining area, *in* Seventh Forum on Geology of Industrial Minerals Proc.: Tallahassee, Florida Bur. Geology, Spec. Pub. 17, p. 51-90.

Weimer, R. J., and Hoyt, J. H., 1964, Burrows of *Callianassa major* Say, geologic indicators of littoral and shallow neritic environments: Jour. Paleontology, v. 38, no. 4, p. 761-767.

Wollast, Roland, Mackenzie, F. T., and Bricker, O. P., 1968, Experimental precipitation and genesis of sepiolite at earth-surface conditions: Am. Mineralogist, v. 53, nos. 9-10, p. 1645-1662.

Yon, J. W., Jr., 1965, The stratigraphic significance of an upper Miocene fossil discovery in Jefferson County, Florida: Southeastern Geology, v. 6, no. 3, p. 167-176.

——1966, Geology of Jefferson County, Florida: Florida Geol. Survey Bull. 48, 119 p.

# TABLES 3-5

**TABLE 3.**—*Stratigraphic sections and mineral estimates from fuller's-earth mines*

Section 1: measured in Waverly Mineral Products Co. mine, 4 miles southeast of Meigs, Ga. (pl. 1, mine A).
Section 2: measured in Cairo Production Co. mine, 1.7 miles northwest of Ochlocknee, Ga. (pl. 1, mine B).
Section 3: measured in Block N mine of Englehard Minerals and Chemicals Corp., 5.5 miles east of Attapulgus, Ga. (pl. 1, mine C).
Section 4: measured in Gun Farm mine of Milwhite Co., 5 miles south-southwest of Attapulgus, Ga. (pl. 1, mine D).
Section 5: measured in La Camelia mine of Englehard Minerals and Chemicals Corp., 6 miles south of Attapulgus, Ga. (pl. 1, mine E).
Section 6: measured in Dresser Minerals Division of Dresser Industries, Inc., mine, 7½ miles south of Attapulgus, Ga. (pl. 1, mine F).
Section 7: measured in Englehard Minerals and Chemicals Corp. mine near Midway, Fla. (pl. 1, mine G).

**Section 1**

[Total thickness of fuller's earth measured, beds 4-9, is 47 ft. 6 in. Altitude of top of bed 4 is 224 ft. Color designations are those of the Munsell Color Co. (1954)]

| Rock description | Thickness | | Mineral estimates (in parts of 10; Tr., trace) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feet | Inches | Palygorskite | Sepiolite | Montmorillonite | Kaolinite | Quartz | Feldspar | Calcite | Dolomite | Fluorapatite | Muscovite |
| 1. Soil, brownish-gray, sandy | | 8 | | | | | | | | | | |
| 2. Sand, light-olive-gray (5Y 6/2) mottled with red (2. 5YR 4/8), fine-grained, clayey, weathered | 5 | 6 | | | | | | | | | | |
| *Miccosukee Formation (?)* | | | | | | | | | | | | |
| 3. Sand, light-gray (5Y 7/7), interlayered with thin beds and laminae of pale-yellow clay (5Y 7/3). Lower half crossbedded, chiefly coarse and very coarse sand with minor sand-clay pebble and clay layers as much as 2 in. thick; contains a few black layers of organic material as much as 1/16 in. thick. Upper half fine- to medium-grained sand interlayered with clay laminae; bedding horizontal | 16 | | | | | | | | | | | |
| *Hawthorn Formation* | | | | | | | | | | | | |
| 4. Clay; lower 5 ft pale olive (5Y 6/3); upper 13 ft light gray (5Y 7/2); massive, jointed, tough, with black manganese (?) films along joints; diatoms form 10 to 20 percent of clay in middle part, sponge spicules and remains of silicoflagellates common | 18 | | | | | | | | | | | |
| Sample: | | | | | | | | | | | | |
| Clay 15 to 18 ft above base | | | | | | | | | | | | |
| Clay 10 to 15 ft above base | | | 1 | Tr. | 5 | 2 | 1 | 1 | | | | |
| Clay 5 to 10 ft above base | | | 2 | | 5 | 2 | 2 | | | | | |
| Clay 1 to 5 ft above base | | | 2 | | 5 | 2 | 1 | | | | | |
| 5. Clay; light gray (5Y 7/2) in lower part, pale yellow (5Y 7/3) in upper part; interbedded with many sand and clay-pebble layers. Clay ranges from 1 to 18 in. in thickness; sand-clay pebble beds range from ½ to 3 in. in thickness; some clay pebbles are as much as 2 in. in longest dimension; most pebbles have gastropod borings, diatoms abundant, sponge spicules common, pelecypod fossils replaced by clay | 10 | | | | | | | | | | | |
| Samples: | | | | | | | | | | | | |
| Clay, upper 7 ft | | | Tr. | Tr. | 6 | 2 | 2 | | | | | |
| Clay, lower 3 ft | | | Tr. | Tr. | 6 | | 2 | Tr. | | | | |
| Clay pebbles | | | 6 | | 4 | Tr. | | | | | | |
| 6. Clay, light-gray (7Y 7/2), tough, somewhat sandy; diatoms very abundant, sponge spicules common; contains a few sand and clay-pebble layers a few of which are as much as 1 in. thick; clay pebbles mostly ½ in. in longest dimension or smaller. Unit cut by clay breccia vein 1 in. thick | 7 | | | | | | | | | | | |
| Samples: | | | | | | | | | | | | |
| Clay, upper 4 ft | | | 2 | | 6 | | 2 | | | | | |
| Clay, lower 3 ft | | | 2 | | 7 | Tr. | 1 | | | | | |
| Clay, breccia | | | 2 | | 5 | 1 | 2 | | | | | |
| 7. Clay, light-gray (7Y 7/2), tough; bedded in layers ⅛ to 14 in. thick; jointed with slickensides along major joints; black manganese (?) films along joints; diatoms abundant, sponge spicules common | 6 | | 2 | | 5 | 1 | 2 | | | | | |
| 8. Clay, light-gray (5Y 7/2) massive, tough; diatoms very abundant, sponge spicules common, silicoflagellate remains rare | 2 | | 2 | | 5 | | 3 | | | | | |
| 9. Clay, light-gray (2.5Y 7/2), tough; lower part massive, upper part poorly bedded; contains a few lenses 1/32 to 3 in. thick of fine-grained gray sand in upper part; diatoms abundant, sponge spicules common | 4 | 6 | 2 | Tr. | 5 | | 3 | | | | | |
| 10. Water level in pit; thickness of clay below water is probably 3 to 5 ft. | | | | | | | | | | | | |
| Total measured | 69 | 8 | | | | | | | | | | |

**Section 2**

[Total thickness of fuller's earth, beds 7-12, is 32 ft. Altitude of top of bed 8 is 239 ft.]

| Rock description | Feet | Inches | Palygorskite | Sepiolite | Montmorillonite | Kaolinite | Quartz | Feldspar | Calcite | Dolomite | Fluorapatite | Muscovite |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Soil, brownish-gray, sandy | | 10 | | | | | | | | | | |
| *Miccosukee Formation (?)* | | | | | | | | | | | | |
| 2. Sand, gray in lower part, yellowish brown in middle, and reddish brown and weathered in upper part; mostly fine to medium grained and clayey but contains some lenses of very coarse sand; lower part in lenticular units and channel-fill deposits | 25 | | | | | | | | | | | |
| *Hawthorn Formation* | | | | | | | | | | | | |
| 3. Clay, pale-yellow (5Y 7/4), plastic | 5-8 | | | | 3 | 3 | 3 | 1 | | | | Tr. |
| 4. Sand, light-gray (5Y 7/2), very clayey | 1-1½ | | | | | | | | | | | |
| 5. Clay, like 2 | 7 | | | | 4 | 3 | 3 | | | | | |
| 6. Sand, like 4 | 1½-2 | | | | | | | | | | | |
| 7. Clay, pale-yellow (5Y 7/4), plastic, diatoms and silicoflagellate remains common (stripped with overburden) | 7 | | | | 5 | 2 | 3 | | | | | |
| 8. Clay, light-gray (5Y 7/2), massive, jointed; black manganese (?) and yellow films along joints; softer than lower clay; diatoms abundant | 6 | | 1 | Tr. | 6 | 1 | 2 | | | | | |

**TABLE 3.**—*Stratigraphic sections and mineral estimates from fuller's-earth mines—Continued*

| Rock description | Thickness | | Mineral estimates (in parts of 10; Tr., trace) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feet | Inches | Palygorskite | Sepiolite | Montmorillonite | Kaolinite | Quartz | Feldspar | Calcite | Dolomite | Fluorapatite | Muscovite |
| **Section 2—continued** | | | | | | | | | | | | |
| 9. Clay, light-gray (5Y 7/2), tough, interbedded with sand-clay-pebble beds; clay beds range from 2 in. to 1 ft in thickness, sand-clay-pebble beds are as much as 2 in. thick; diatoms abundant, sponge spicules and silicoflagellate remains common | 4 | 4 | | | | | | | | | | |
| Samples: | | | | | | | | | | | | |
| Clay | | | 1 | 1 | 6 | Tr. | 2 | Tr. | Tr. | | 2 | |
| Clay pebbles | | | Tr. | 3 | 4 | | 2 | | | | | |
| 10. Clay, light-gray (5Y 7/2), massive, tough, jointed; diatoms abundant | 4 | 8 | 1 | Tr. | 5 | Tr. | 3 | 1 | | | | |
| 11. Clay, light-gray (5Y 7/2) massive, tough, jointed; contains a few sand lenses ½ X 8 in. in upper half; diatoms abundant, sponge spicules and silicoflagellate remains common | 5 | | 1 | Tr. | 5 | Tr. | 3 | | | | | |
| 12. Clay, light-gray (5Y 7/2), massive, tough, jointed; black manganese (?) films along joints; diatoms abundant, sponge spicules common | 5 | | | | | | | | | | | |
| Samples: | | | | | | | | | | | | |
| Upper 4 ft | | | 1 | ½ | 5 | ½ | 2 | | | | | |
| Lower 1 ft | | | 2 | Tr. | 6 | | 2 | | | | | |
| Sand, light-gray (5Y 7/2), fine-grained, hard | | | | | | | | | | | | |
| Total measured | 74 | 10 | | | | | | | | | | |
| **Section 3** [Total thickness of clay measured, beds 5-7, is 15 ft 6 in. Altitude of top of bed 6 is 173 ft] | | | | | | | | | | | | |
| 1. Soil, dark-gray | | 8 | | | | | | | | | | |
| *Hawthorn Formation (?)* | | | | | | | | | | | | |
| 2. Sand, light-gray, fine- to medium-grained, weathered | 2 | | | | | | | | | | | |
| 3. Sand, brownish-gray, medium-grained, clayey | 4 | | | | | | | | | | | |
| 4. Limestone, white, very sandy; contains molds and casts of marine fossils | 2 | | | | | | | | | | | |
| 5. Clay, light-gray (5Y 7/1), plastic; burrows of *Callianassa* or other marine animals abundant and cause the clay to have a brecciated appearance; calcite-filled desiccation cracks abundant in upper 4 in. (stripped with overburden) | 7 | | 2 | Tr. | 2 | 3 | 3 | | | | | |
| 6. Clay, light-gray (5Y 7/2), poorly bedded; contains a few white calcite crystals in lower part, black manganese (?) films along joints | 5 | | 6 | | 1 | | 1 | | 1 | 1 | Tr. | |
| 7. Clay, light-olive-gray (5Y 6/2), moderately hard, jointed; upper part contains a few small lenses of light-gray silt and white ovoid lenses of limestone | 3 | 6 | 5 | | 2 | Tr. | 2 | | | | | |
| 8. Sand, light-gray (5Y 7/2), fine-grained, silty and clayey; upper part contains molds of marine fossils | | | | | | | | | | | | |
| Sample: | | | | | | | | | | | | |
| 2 $\mu$m fraction | | | 10 | | | | | | | | | |
| Total measured | 24 | 2 | | | | | | | | | | |
| **Section 4** [Thickness of clay, bed 13, 7 ft; beds 15 and 16, somewhat greater than 4 ft 6 in. Altitude of top of bed 13 is 184 ft] | | | | | | | | | | | | |
| *Post-Miocene deposits* | | | | | | | | | | | | |
| 1. Soil, brownish-gray, sandy | | 10 | | | | | | | | | | |
| 2. Sand, gray, fine- to medium-grained, weathered | 3 | | | | | | | | | | | |
| *Miccosukee Formation (?)* | | | | | | | | | | | | |
| 3. Sand, yellow (5Y 7/2), medium- to coarse-grained | 15 | | | | | | | | | | | |
| *Hawthorn Formation* | | | | | | | | | | | | |
| 4. Clay, light-gray (5Y 7/2), abundant brown stains, plastic | | 3 | | | | | | | | | | |
| 5. Sand, yellow (2.5Y 7/8); interlayered with plastic clay laminae; fine to medium grained | 20 | | | | | | | | | | | |
| 6. Clay, light-gray (5Y 7/2); somewhat darker in upper part; upper part sandy, plastic | 11 | | | | 4 | 3 | | 3 | | | | |
| 7. Sand, light-gray (5Y 7/2); somewhat lighter in upper part; fine grained | 6 | | | | | | | | | | | |
| 8. Limestone, white, hard; composed mainly of internal molds of marine fossils | 2 | | | | | | | | | | | |
| 9. Sand, pale-olive (5Y 6/3); contains abundant marine fossils and sharks' teeth | 3 | | | | | | | | | | | |
| 10. Limestone, like 8 | 2 | 6 | | | | | | | | | | |
| 11. Sand, more blue than gray (5Y 5/1); clayey in upper and lower parts; burrows of *Callianassa* or other marine animals abundant | 4 | 10 | | | | | | | | | | |
| 12. Clay, more blue than gray (5Y 5/1); hard; contains boxwork of calcite veins so abundant it makes up nearly half of bed | 3 | | | | | | | | | | | |
| 13. Clay, more blue than gray (5Y 5/1), hard, jointed | 7 | | | | | | | | | | | |
| 14. Sandstone, more blue than gray (5Y 5/1), clayey, calcite-cemented; bed 10 in. thick in middle contains abundant marine fossils | 11 | | | | | | | | | | | |
| 15. Clay, more blue than gray (5Y 5/1), hard, brittle, two beds of white chalky dolomite each approximately 2 in. thick and few fine-grained quartz sand lenses as much as 1½. in. thick in lower half | 4 | 6 | | | | | | | | | | |
| Sample: | | | | | | | | | | | | |
| Clay, upper 3 ft | | | 9 | | Tr. | | 1 | | | | | |
| Clay, lower 1½ ft | | | 9 | | | | | | | | | |
| Chalky dolomite | | | 9 | | | | | | | 1 | | |
| Water level; thickness of clay below water level is probably about 3 ft. | | | | | | | | | | | | |
| Total measured | 93 | 11 | | | | | | | | | | |

**TABLE 3.**—*Stratigraphic sections and mineral estimates from fuller's-earth mines*—*Continued*

| Rock description | Thickness | | Mineral estimates (in parts of 10; Tr., trace) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feet | Inches | Palygorskite | Sepiolite | Montmorillonite | Kaolinite | Quartz | Feldspar | Calcite | Dolomite | Fluorapatite | Muscovite |
| **Section 5** [Thickness of clay, bed 21, where not cut by channel fill, 10 ft; beds 27-30, 9 ft 10 in. Altitude of top of bed 21 is 187 ft] | | | | | | | | | | | | |
| 1. Soil, dark-brownish-gray, sandy | 1 | | | | | | | | | | | |
| *Miccosukee Formation (?)* | | | | | | | | | | | | |
| 2. Sand, reddish, clayey, nonbedded, weathered | 5 | | | | | | | | | | | |
| 3. Clay and sand interbedded, light-gray and brown variegated; contains scattered white and light-gray chert nodules; thickness irregular | 1-3 | | | | | | | | | | | |
| 4. Sand, brownish-red, fine- to medium-grained, massive; contains burrows of *Callianassa;* thickness irregular | 1-2 | | | | | | | | | | | |
| 5. Sand and clay interbedded; sand is brownish red, mainly medium grained but contains some gravel; clay is light gray and yellowish gray; thickness irregular | 1-2 | | | | | | | | | | | |
| 6. Sand, brownish-red, crossbedded; mainly coarse grained with some gravel in upper part; contains a few burrows of *Callianassa* | 18 | | | | | | | | | | | |
| 7. Nodular zone consisting of spheroidal wavellite concretions ½ to 2 in. in diameter; concretions coalesce to form a ledge 4 to 6 in. thick | | 4 | | | | | | | | | | |
| 8. Sand, reddish-brown, medium to very coarse grained; most grains coated with red iron oxide; crossbedded | 12 | | | | | | | | | | | |
| *Hawthorn Formation* | | | | | | | | | | | | |
| 9. Sand and clay interbedded, mostly yellow (10YR 7/8); lower part crossbedded, contains black lithiophorite accumulations along bedding; clay abundant in lower part, where beds are as much as 2 in. thick; clay higher in unit is mostly in laminae; uppermost zone 1 to 2 ft. thick is weathered white and consists of fine-grained sand and kaolin, indicating an unconformity | 30 | | | | | | | | | | | |
| Samples: | | | | | | | | | | | | |
| White weathered zone at top | | | | | | 6 | 4 | | | | | |
| Clay bed in lower part | | | | | 7 | 3 | | | | | | |
| 10. Sand, brownish-yellow (10YR 6/8), fine-grained, very clayey, poorly bedded | 4 | | | | | | | | | | | |
| 11. Sand, light-gray (10YR 7/2), very fine grained, nonbedded | 14 | | | | | | | | | | | |
| 12. Limestone, light-yellowish-brown (10YR 6/4), sandy, soft | 1 | 6 | | | | | | | | | | |
| 13. Limestone, light-yellowish-brown (2.5Y 6/4), hard, very sandy; consists mainly of internal molds of fossils, contains large *Pecten;* brown and gray phosphate pellets common | 2 | | | | | | | | | | | |
| 14. Limestone, light-yellowish-brown (10YR 6/4), very sandy, soft | 1 | 8 | | | | | | | | | | |
| 15. Limestone, light-gray (5YR 6/1), soft, fossilierous | 1 | 6 | | | | | | | | | | |
| 16. Limestone, light-gray (5Y 6/1), hard, phosphatic, sandy; a persistent zone of black muck or gel occurs in vugs and cracks in upper part; contains abundant marine fossils; *Sorites* present | 1 | 8 | | | | | | | | | | |
| 17. Clay, more blue than gray (5Y 5/1), hard; contains irregular boxwork of white calcite veins | 2 | 4 | | | 4 | 1 | 5 | | | | | |
| 18. Sand, dark-greenish-gray, clayey; contains abundant marine fossils | 1 | 8 | | | | | | | | | | |
| 19. Sand, dark-greenish-gray, clayey | 3 | 6 | | | | | | | | | | |
| 20. Clay, more blue than gray (5Y 5/1), hard; contains irregular boxwork of white calcite veins | 7 | | | | | | | | | | | |
| Sample: | | | | | | | | | | | | |
| Clay | | | 6 | Tr. | 4 | | | | | | | |
| 21. Clay, mostly olive gray (5Y 6/2), hard; contains two persistant layers of white chalky dolomite 2 to 4 in. thick in upper part; cut by irregular channel-fill-type lenticular deposit. The lenticular deposit is composed of fine to very coarse sand units and carbonate and phosphatic materials, and has burrows of *Callianassa;* fillings of burrows contain Foraminifera of Chiopla age (middle Miocene) | 10 | | | | | | | | | | | |
| Samples: | | | | | | | | | | | | |
| Clay | | | 8 | | Tr. | | 2 | | | | | |
| Chalky dolomite | | | 1 | | | | | | | | | |
| 22. Limestone, pale-yellow (5Y 8/3), abundant black clay films along joints; thickness irregular | ½-1 | | | | | | | | | | | |
| Sample: | | | | | | | | | | | | |
| Clay film | | | | | 7 | 1 | 2 | | | | | |
| 23. Clay, pale-olive (5Y 6/3); minor black manganese (?)stains along joints; contains scattered algal heads consisting of white chalky dolomite as much as 1½ in. thick and crystals of a carbonate mineral | 4 | 2 | | | | | | | | | | |
| Samples: | | | | | | | | | | | | |
| Clay | | | 7 | | | | 1 | | 2 | | | |
| Dolomite forming algal head | | | 3 | | | | 2 | | | 5 | | |
| 24. Clay, light-gray (5Y 7/2), hard; contains phosphate nodules; a layer of white chalky dolomite occurs in upper part | | 8 | 6 | | | | 2 | | | 2 | | |
| 25. Sandstone, white (5Y 8/2), mostly fine grained, calcite-cemented; contains phosphate nodules, fish remains, and scattered chunks of clay | 3 | 2 | | | | | | | | | | |
| 26. Clay, pale-olive (5Y 6/3); somewhat darker in upper part; upper contact irregular, upper part contains stringers of overlying sandstone, appears churned by burrowing marine animals, probably *Callianassa* | 1 | 10 | 1 | Tr. | 7 | | 2 | | | | | |
| 27. Clay, gray (5Y 5/1); contains much black organic matter, plastic; has brecciated appearance | | 10 | 1 | | 7 | | 2 | | | | | |
| 28. Clay, pale-olive (5Y 6/3) in lower part, gray (5Y 5/1) in upper part; plastic; some black organic stains near base | 2 | | 9 | | | | 1 | | | | | |
| 29. Clay, light-gray (5Y 6/2), plastic | 4 | 6 | | | | | | | | | | |
| 30. Clay, gray (5Y 6/1), plastic; contains two white chalky dolomite zones 1 to 4 in. thick, one zone near base and one 1 ft above base; a few small sand lenses 1 to 10 in. thick in upper part | 2 | 6 | | | | | | | | | | |
| Samples: | | | | | | | | | | | | |
| Clay | | | 7 | | Tr. | | 1 | | 1 | 1 | | |
| Chalky dolomite | | | 2 | | | | | | | 8 | | |

**Table 3.**—*Stratigraphic sections and mineral estimates from fuller's-earth mines—Continued*

| Rock description | Thickness | | Mineral estimates (in parts of 10; Tr., trace) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feet | Inches | Palygorskite | Sepiolite | Montmorillonite | Kaolinite | Quartz | Feldspar | Calcite | Dolomite | Fluorapatite | Muscovite |
| **Section 5—Continued** | | | | | | | | | | | | |
| 31. Sandstone, white (5Y 8/2), hard, clayey | | | | | | | | | | | | |
| Total measured (rounded) | 140 | | | | | | | | | | | |
| **Section 6** [Thickness of clay, beds 6 and 7, is 11 ft. Altitude of top of bed 6 is 145 ft] | | | | | | | | | | | | |
| 1. Soil, dark-brownish-gray, sandy | 1 | | | | | | | | | | | |
| *Miccosukee Formation (?)* | | | | | | | | | | | | |
| 2. Sand, dark-gray and gray in lower part, grades upward into yellowish-brown clayey sand; a zone 2 to 5 ft above base contains lenticular units of very coarse sand and gravel | 13 | | | | | | | | | | | |
| *Hawthorn Formation* | | | | | | | | | | | | |
| 3. Sand, grayish-brown, fine- to medium-grained; stingray teeth and phosphatic pellets common in lower part | 5 | | | | | | | | | | | |
| 4. Sand, bluish-gray, fine-grained; echinoid spines and plates, fish teeth, and pelecypod fossils abundant | 3 | | | | | | | | | | | |
| 5. Clay, more blue than gray (5Y 5/1), hard; calcite jointfill accumulations as much as 1 in. thick extend downward from top as much as 1½ ft; joint fills have rounded carbonate pebbles in calcite matrix indicating origin as desiccation-crack fillings | 2 | 6 | | | | | | | | | | |
| Samples: | | | | | | | | | | | | |
| Joint fillings | | | | | | | | | 10 | | | |
| Clay | | | | | 6 | 1 | 2 | | | | | |
| 6. Clay, more blue than gray (5Y 5/1), blocky, hard | 10 | | | | | | | | | | | |
| Samples: | | | | | | | | | | | | |
| Clay 5 to 10 ft above base | | | 2 | | 5 | 1 | 2 | | | | | |
| Clay 1 to 5 ft above base | | | 3 | | 4 | 1 | 2 | | | | | |
| Clay 0 to 1 ft above base | | | 4 | | 4 | 1 | 1 | | | | | |
| 7. Clay, more blue than gray (5Y 5/1), blocky, hard; a zone of white dolomite concretions as much as 2 × 8 in. at top; thickness somewhat irregular | 1-1½ | | | | | | | | | | | |
| 8. Dolomite, white, dense; thickness somewhat irregular | | 2-8 | 1 | | | | | | | 9 | | |
| 9. Clay, more blue than gray (5Y 5/1), blocky, hard | 5 | | | | | | | | | | | |
| 10. Water level. | | | | | | | | | | | | |
| Total measured (rounded) | 41 | | | | | | | | | | | |
| **Section 7** [Total thickness of clay, beds 12 and 13, is 9 ft 4 in.; thickness of clay section mined is 7 ft 2 in. Altitude of top of bed 13 is 130 ft] | | | | | | | | | | | | |
| 1. Soil, dark-brownish-gray, sandy | | 10 | | | | | | | | | | |
| *Miccosukee Formation (?)* | | | | | | | | | | | | |
| 2. Sand, reddish-brown with irregular light-gray spots, weathered; lower part contains a basal gravel of hard cemented sand chunks as much as 3 in. long; rests unconformably on lower beds | 8 | | | | | | | | | | | |
| *Hawthorn Formation* | | | | | | | | | | | | |
| 3. Clay, light-gray (10YR 7/2), plastic, slickensided; upper part stained brown along joints, lenticular | 0-8 | | | | 4 | 4 | 2 | | | | | |
| 4. Sand, yellowish-red (5YR 4/8), light-gray along joints, fine- to medium-grained, clayey | 5 | | | | | | | | | | | |
| 5. Sand, yellow (10YR 7/8), upper part darker, fine-grained; contains a few rounded white clay lumps as much as ¾ in. long in upper part | 12 | | | | | | | | | | | |
| 6. Sand, white (5Y 8/1); some yellow staining in upper part; fine to medium grained | 3 | 6 | | | | | | | | | | |
| 7. Sand, pale-yellow (5Y 7/3), mottled with yellow and reddish-brown; very clayey; thickens to 8 ft in nearby area. Sand is fine to medium grained subangular quartz | 4 | 6 | | | | | | | | | | |
| 8. Clay, pale-yellow (5Y 7/3), very plastic, slickensided | | 9 | | | 5 | | 4 | 1 | | | | |
| 9. Sand, pale-yellow (5Y 7/3), clayey; black manganese (?) stains in upper part, slickensided | | 8 | | | | | | | | | | |
| 10. Clay like 8 | | 7 | | | 5 | | 4 | 1 | | | | |
| 11. Sand, like 9 | 2 | 1 | | | | | | | | | | |
| 12. Clay, light-gray (5Y 7/2); abundant manganese (?) stains along joints; very sandy in upper part; plastic (removed with overburden) | 2 | 2 | | | | | | | | | | |
| Samples: | | | | | | | | | | | | |
| Upper 1 ft | | | | | | | | | | | | |
| Lower 1 ft., 2 in | | | Tr. | | 7 | | 3 | | | | | |
| 13. Clay, light-gray (5Y 7/2), plastic; some black manganese (?) stains along joints in lower part | 7 | 2 | | | | | | | | | | |
| Samples: | | | | | | | | | | | | |
| Upper 4 ft, 2 in | | | 7 | 1 | | | 1 | | | | 1 | |
| Middle 1 ft, 6 in | | | 9 | | | | 1 | | | | Tr. | |
| Lower 1 ft, 6 in | | | 8 | | | | 2 | | | | | |
| Sand, white (2.5Y 8/2), fine-grained, very clayey, hard | | | | | | | | | | | | |
| Total measured | 55 | 3 | | | | | | | | | | |

TABLE 4.—*Logs and mineral estimates of samples from auger holes in Georgia*

| Rocks penetrated | Thickness | | Mineral estimates (in parts of 10; Tr., trace) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Feet | Inches | Palygorskite | Sepiolite | Montmorillonite | Kaolinite | Quartz | Feldspar | Calcite | Dolomite |
| **Auger hole 1 (pl. 1), 6 miles east of Meigs, Colquitt County** [Altitude top of bed 2, by topographic map, 225 ft.] | | | | | | | | | | |
| 1. Sand, brown, fine- to medium-grained | 3 | 6 | -- | -- | -- | -- | -- | -- | -- | -- |
| 2. Clay, yellowish-brown and light-gray interlaminated, plastic | 5 | -- | -- | -- | 5 | 5 | Tr. | -- | -- | -- |
| 3. Clay, light-gray, plastic | 5 | -- | -- | -- | 6 | 1 | 3 | -- | -- | -- |
| 4. Clay, light-gray, very plastic (poor recovery) | 30 | -- | 1 | -- | 7 | -- | 2 | -- | -- | -- |
| 5. Clay, light-gray, hard | 18 | 6 | 2 | -- | 3 | -- | 5 | Tr. | -- | -- |
| 6. Clay, light-brownish-gray, plastic | 1 | -- | Tr. | -- | 6 | -- | 4 | -- | -- | -- |
| 7. Clay, brown, contains chert | | | | | | | | | | |
| Total | 63 | 6 | -- | -- | -- | -- | -- | -- | -- | -- |
| **Auger hole 2 (pl. 1), 4.5 miles southeast of Meigs, Thomas County** [Altitude top of bed 2, by aneroid, 224 ft.] | | | | | | | | | | |
| 1. Sand, yellowish-brown, fine- to medium-grained | 3 | 6 | -- | -- | -- | -- | -- | -- | -- | -- |
| 2. Clay, reddish-brown and light-gray, stiff plastic | 5 | -- | -- | -- | 3 | 3 | 4 | -- | -- | -- |
| 3. Clay, light-gray, plastic | 12 | -- | -- | -- | 6 | 1 | 3 | -- | -- | -- |
| 4. Clay, light-gray, very plastic (poor recovery) | 20 | -- | 1 | -- | 5 | 1 | 3 | -- | -- | -- |
| 5. Clay, gray, very hard | 12 | -- | 2 | -- | 5 | -- | 2 | 1 | -- | -- |
| Total | 52 | 6 | -- | -- | -- | -- | -- | -- | -- | -- |
| **Auger hole 3 (pl. 1), 3.5 miles west of Ochlockonee, Thomas County** [Altitude top of bed 3, by aneroid, 236 ft.] | | | | | | | | | | |
| 1. Road fill | 1 | 6 | -- | -- | -- | -- | -- | -- | -- | -- |
| 2. Sand, red, fine-grained, soft | 2 | 6 | -- | -- | -- | -- | -- | -- | -- | -- |
| 3. Clay, light-gray, stiff plastic | 10 | -- | -- | -- | 7 | 1 | 2 | -- | -- | -- |
| 4. Clay, light-yellowish-gray, plastic | 9 | -- | ½ | -- | 7 | ½ | 2 | -- | -- | -- |
| 5. Clay, light-bluish-gray, plastic | 23 | -- | -- | -- | 9 | -- | 1 | -- | -- | -- |
| 6. Clay, light-bluish-gray, chunky | 4 | -- | Tr. | -- | 5 | -- | 2 | -- | -- | 3 |
| 7. Clay, light-bluish-gray, chunky; contains abundant shell chunks | 6 | -- | 2 | -- | 6 | -- | 1 | 1 | Tr. | -- |
| 8. Dolomite, white, marly | 2 | -- | 2 | -- | -- | 1 | -- | -- | -- | 7 |
| Total | 58 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| **Auger hole 4 (pl 1), 6 miles north of Thomasville, Thomas County** | | | | | | | | | | |
| 1. Sand, yellowish-brown, fine- to medium-grained, clayey | 3 | 6 | -- | -- | -- | -- | -- | -- | -- | -- |
| 2. Sand, reddish-brown and light-gray, clayey | 8 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 3. Clay, red and light-gray, interlaminated, stiff plastic | 2 | -- | -- | -- | 2 | 5 | 3 | -- | -- | -- |
| 4. Clay, light-gray and light-brown interlayered, plastic | 2 | 6 | -- | -- | 5 | 3 | 2 | -- | -- | -- |
| 5. Sand, light-brown, fine- to medium-grained, clayey | 7 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 6. Clay, light-gray, stiff plastic | 15 | -- | -- | -- | 5 | -- | 3 | 2 | -- | -- |
| 7. Clay, light-gray, very plastic (poor recovery) | 15 | -- | -- | -- | 5 | -- | 4 | 1 | -- | -- |
| 8. Clay, light-gray; hard chunks abundant | 10 | -- | Tr. | Tr. | 7 | -- | 2 | 1 | -- | -- |
| Total | 63 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| **Auger hole 5 (pl. 1), 5.5 miles northwest of Whigham, Grady County** [Altitude top of bed 5, by aneroid, 217 ft.] | | | | | | | | | | |
| 1. Sand, reddish-brown, fine- to medium-grained | 4 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 2. Clay, red and gray mottled, stiff plastic | 2 | -- | -- | -- | 7 | -- | 3 | -- | -- | -- |
| 3. Sand, light-yellowish-brown, fine- to medium-grained | 3 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 4. Sand, brownish-gray; darker in lower part; mostly fine grained, clayey | 5 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 5. Clay, dark-brown, stiff plastic; contains chunks of carbonized wood | 1 | 6 | -- | -- | 7 | -- | 3 | -- | -- | -- |
| 6. Sand, brownish-gray, mostly fine grained | 5 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 7. Clay, light-gray, sandy, plastic | 5 | -- | -- | -- | 7 | -- | 3 | -- | -- | -- |
| 8. Clay and limestone, brownish-gray, sandy, hard | 12 | -- | -- | -- | 4 | -- | 2 | -- | 4 | -- |
| Total | 37 | 6 | -- | -- | -- | -- | -- | -- | -- | -- |

TABLE 4.—*Logs and mineral estimates of samples from auger holes in Georgia*—*Continued*

| Rocks penetrated | Thickness | | Mineral estimates (in parts of 10; Tr., trace) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Feet | Inches | Palygorskite | Sepiolite | Montmorillonite | Kaolinite | Quartz | Feldspar | Calcite | Dolomite |
| **Auger hole 6 (pl. 1), 4.5 miles northeast of Whigham, Grady County** [Altitude top of bed 2, from topographic map, 243 ft.] | | | | | | | | | | |
| 1. Road fill | 1 | – | – | – | – | – | – | – | – | – |
| 2. Clay, light-brown, sandy, plastic | 5 | – | – | – | 4 | – | 6 | – | – | – |
| 3. Clay, light-grayish-brown, plastic | 5 | – | – | – | 6 | – | 4 | – | – | – |
| 4. Clay, light-gray, plastic | 12 | 6 | 1 | – | 6 | Tr. | 3 | – | – | – |
| 5. Clay, light-brownish gray, plastic | 10 | – | 4 | – | 3 | – | 3 | – | – | – |
| 6. Clay, light-gray, plastic | 15 | – | 5 | – | 3 | – | 2 | – | – | – |
| 7. Clay, light-gray, very plastic (poor recovery) | 24 | – | – | – | 2 | – | 4 | – | 2 | 2 |
| 8. Sandstone, gray and brownish-gray, calcite-cemented | – | 6 | 1 | – | 3 | – | 3 | – | 1½ | 1½ |
| Total | 73 | – | – | – | – | – | – | – | – | – |
| **Auger hole 7 (pl. 1), 4 miles northeast of Whigham, Grady County** [Altitude top of bed 4, by aneroid, 228 ft.] | | | | | | | | | | |
| 1. Sand and road fill | 2 | 6 | – | – | – | – | – | – | – | – |
| 2. Clay, light-brownish-gray, sandy, stiff plastic | 1 | – | – | – | – | – | – | – | – | – |
| 3. Clay, upper part gray, lower part brownish-gray, very stiff plastic | 5 | – | – | – | – | – | – | – | – | – |
| 4. Clay, light-gray, very stiff plastic | 5 | – | – | – | 7 | – | 3 | Tr. | – | – |
| 5. Clay, light-gray, hard, chunky | 5 | – | 4 | – | 5 | – | 1 | – | – | – |
| 6. Clay, light-gray with some gray, hard, chunky | 5 | – | 4 | – | 3 | – | – | – | 1 | 2 |
| 7. Clay, very light gray, hard | 5 | – | 5 | – | 3 | – | 1 | – | – | 1 |
| 8. Clay, light-gray, chunky | 5 | – | 7 | – | 2 | – | 1 | – | – | – |
| 9. Clay, light-brownish-gray, hard | 10 | – | 2 | – | 5 | – | 2 | 1 | – | – |
| Total | 43 | 6 | – | – | – | – | – | – | – | – |
| **Auger hole 8 (pl. 1), 4 miles northeast of Cairo, Grady County** [Altitude top of bed 3, by aneroid, 205 ft.] | | | | | | | | | | |
| 1. Road fill | 2 | – | – | – | – | – | – | – | – | – |
| 2. Sand, yellow, mostly fine grained | 6 | – | – | – | – | – | – | – | – | – |
| 3. Clay, very light yellowish gray, plastic | 10 | – | – | – | 5 | – | 4 | 1 | – | – |
| 4. Clay, very light yellowish gray and very plastic; light-brown, contains some shell fragments | 5 | – | 7 | – | – | – | 3 | – | – | – |
| 5. Clay, light-gray; contains shell fragments; very plastic; poor recovery | 9 | – | 5 | – | 1 | – | 1 | – | – | 3 |
| Total | 32 | – | – | – | – | – | – | – | – | – |
| **Auger hole 9 (pl. 1), 2 miles southeast of Cairo, Grady County** [Altitude top of bed 2, by aneroid, 224 ft] | | | | | | | | | | |
| 1. Sand and road fill, red | 3 | 6 | – | – | – | – | – | – | – | – |
| 2. Clay, light-brown and gray mixed, stiff plastic | 1 | – | – | – | 7 | – | 3 | – | – | – |
| 3. Clay, gray, very sandy | 7 | – | – | – | – | – | – | – | – | – |
| 4. Clay, gray, plastic | 16 | – | – | – | 7 | 1 | 2 | – | – | – |
| 5. Clay, brownish-gray, plastic; contains a few hard chunks | 4 | – | 5 | – | 3 | – | 2 | – | – | – |
| 6. Clay, gray; abundant pelecypod shells | 2 | – | 5 | – | 3 | – | 2 | – | – | – |
| 7. Clay, light-gray and very light gray, plastic; contains hard chunks | 12 | – | 1 | Tr. | 3 | – | 3 | – | – | 3 |
| 8. Clay, light-gray, mostly plastic; sandy in lower part | 6 | – | 1 | 1 | 4 | – | 1 | – | – | 3 |
| 9. Clay, gray; contains abundant pelecypod shells | 2 | – | 1 | 2 | – | – | 3 | – | – | 4 |
| 10. Hard rock | – | – | – | – | – | – | – | – | – | – |
| Total | 53 | 6 | – | – | – | – | – | – | – | – |
| **Auger hole 10 (pl. 1), 7.5 miles south-southwest of Cairo, Grady County** [Altitude top of bed 5, by aneroid 187 ft.] | | | | | | | | | | |
| 1. Sandstone, fine-grained, red and brown | 3 | 6 | – | – | – | – | – | – | – | – |
| 2. Sand, light-yellowish-brown, fine- to medium-grained | 5 | – | – | – | – | – | – | – | – | – |
| 3. Sand, clayey, and sandy clay mixed, light-yellowish-brown | 5 | – | – | – | – | – | – | – | – | – |
| 4. Sand, light-yellowish-brown, fine- to medium-grained, clayey | 7 | – | – | – | – | – | – | – | – | – |
| 5. Clay, very light yellowish gray, plastic | 13 | – | – | – | 3 | – | 6 | 1 | – | – |
| 6. Clay, very light gray, very plastic | 10 | – | – | – | 4 | – | 5 | 1 | – | – |
| 7. Clay, light-gray, soft plastic, sandy | 6 | 6 | – | – | 3 | – | 7 | Tr. | – | – |
| 8. Limestone, white, plastic | 2 | – | – | – | 3 | – | 1 | Tr. | 5 | 1 |
| 9. Hard rock | – | – | – | – | – | – | – | – | – | – |
| Total | 52 | – | – | – | – | – | – | – | – | – |

**Table 4.**—*Logs and mineral estimates from auger holes in Georgia—Continued*

| Rocks penetrated | Thickness | | Mineral estimates (in parts of 10; Tr., trace) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Feet | Inches | Palygorskite | Sepiolite | Montmorillonite | Kaolinite | Quartz | Feldspar | Calcite | Dolomite |
| **Auger hole 11 (pl. 1), 6 miles south of Cairo, Grady County** [Altitude top of bed 9, by aneroid, 163 ft.] | | | | | | | | | | |
| 1. Soil and sand, brown and red | 4 | 6 | -- | -- | -- | -- | -- | -- | -- | -- |
| 2. Sand, reddish-brown, fine- to medium-grained, very clayey | 4 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 3. Clay, light-yellowish-brown in upper part, yellowish-brown in lower part; stiff plastic | 3 | -- | -- | -- | 6 | 1 | 3 | -- | -- | -- |
| 4. Sand, light-brown, fine-grained, clayey | 12 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 5. Sand, very light brownish gray, clayey | 11 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 6. Sand, very light gray, fine-grained, clayey | 10 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 7. Sand, light-brownish-gray, clayey | 1 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 8. Sand, very light gray, fine- to medium-grained, clayey | 5 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 9. Clay, dark-gray, stiff plastic | 5 | -- | -- | -- | 8 | 2 | -- | -- | -- | -- |
| 10. Clay, very dark gray, plastic | 4 | -- | 1 | -- | 5 | 1 | 3 | -- | -- | -- |
| 11. Clay, dark-gray, some light-gray; plastic with hard chunks | 2 | -- | -- | -- | 4 | 3 | 3 | -- | -- | -- |
| 12. Clay, very dark gray and gray mixed, very plastic (poor recovery) | 2 | 6 | 1 | -- | 4 | 2 | -- | -- | -- | 3 |
| Total | 73 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| **Auger hole 12 (pl. 1), 10.5 miles south of Cairo, Grady County** [Altitude top of bed 2, by aneroid, 135 ft.] | | | | | | | | | | |
| 1. Sandy, red and brownish-red, clayey | 6 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 2. Clay, light-brown, very clayey | 6 | -- | -- | -- | 3 | -- | 7 | -- | -- | -- |
| 3. Clay, light-gray, stiff plastic | 1 | 6 | -- | -- | 6 | -- | 4 | -- | -- | -- |
| 4. Clay, dark-brown, sandy, stiff plastic | 7 | -- | -- | -- | 6 | -- | 4 | -- | -- | -- |
| 5. Clay with thin limy layers, light-gray, hard | 2 | -- | -- | -- | 5 | -- | 4 | -- | 1 | -- |
| 6. Clay with soft limestone, white, chalky | 2 | -- | 5 | -- | 1 | -- | -- | -- | 3 | 1 |
| Total | 24 | 6 | -- | -- | -- | -- | -- | -- | -- | -- |
| **Auger hole 13 (pl. 1), 7 miles south of Bainbridge, Decatur County** [Altitude top of bed 2, by aneroid, 260 ft.] | | | | | | | | | | |
| 1. Sand, light-brown and brown, fine- to medium-grained, clayey | 3 | 6 | -- | -- | -- | -- | -- | -- | -- | -- |
| 2. Clay, light-brown, brown, and light-gray mixed, stiff plastic | 3 | -- | -- | -- | 3 | 3 | 4 | -- | -- | -- |
| 3. Clay, light-gray, stiff plastic | 7 | -- | -- | -- | 5 | -- | 4½ | ½ | -- | -- |
| 4. Clay, light-gray, plastic, very sandy; contains one layer of coarse-grained sand 5 in. thick in lower part | 12 | -- | -- | -- | 6 | -- | 3 | 1 | -- | -- |
| 5. Sand, light-brown, clayey | 3 | -- | -- | -- | 4 | -- | 5 | 1 | -- | -- |
| 6. Sand, grayish-brown, clayey | 10 | -- | -- | -- | 3 | -- | 7 | -- | -- | -- |
| 7. Sand, light-gray, very clayey | 25 | 6 | Tr.( ) | -- | 3 | -- | 6 | -- | 1 | -- |
| 8. Limestone, white; mostly soft with some hard chunks | 2 | -- | -- | -- | 2 | -- | -- | -- | 8 | -- |
| Total | 66 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| **Auger hole 14 (pl. 1), 7 miles southwest of Whigham, Decatur County** [Altitude top of bed 2, by aneroid, 229 ft.] | | | | | | | | | | |
| 1. Sand, yellowish-brown, fine- to medium-grained | 5 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 2. Clay, light-gray, plastic, very sandy | 3 | 6 | -- | -- | -- | -- | -- | -- | -- | -- |
| 3. Clay, light-yellowish-brown, very sandy, plastic | 1 | 6 | -- | -- | -- | -- | -- | -- | -- | -- |
| 4. Clay, light-gray, very sandy | 3 | 6 | -- | -- | -- | -- | -- | -- | -- | -- |
| 5. Clay, light-gray, plastic | 12 | -- | -- | -- | 5 | 2 | 3 | -- | -- | -- |
| 6. Clay, light-gray, hard; sandy in lower part; poor recovery | 37 | -- | Tr. | -- | 7 | -- | 3 | -- | -- | -- |
| 7. Sandstone, light-gray, mostly fine grained, hard | 5 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Total | 67 | 6 | -- | -- | -- | -- | -- | -- | -- | -- |

**TABLE 5.**—*Mineral estimates of chips of clay and fuller's earth from well cuttings and drill cores at the Florida Bureau of Geology*

[Expressed in parts of 10, Tr. trace. All wells are in Florida (pl. 1)]

| Well, or core, and sample description | | Palygorskite | Sepiolite | Montmorillonite | Kaolinite | Quartz | Feldspar | Calcite | Dolomite | Other |
|---|---|---|---|---|---|---|---|---|---|---|
| W1786, 2½ miles northwest of Greensboro, Gadsden County. Altitude of top of clay is 134 ft above sea level. | | | | | | | | | | |
| *Depth interval (ft)* | | | | | | | | | | |
| 150-160 | Clay, gray, plastic | | | 8 | | 2 | | | | |
| W-7458, 3 miles southwest of Greensboro, Gadsden County. Altitude of top of clay at depth of 86 ft is 169 ft above sea level. | | | | | | | | | | |
| *Depth interval (ft)* | | | | | | | | | | |
| 55 | Clay, dark-gray; 6 in. thick | | | 7 | | 3 | | | | |
| 86-87 | Clay, greenish-gray, phosphatic | 3 | | 3 | | 4 | | | | |
| 104-109 | Clay, light-gray, dolomitic | 2 | Tr. | 2 | | 3 | | | 3 | |
| W7539, 5½ miles south of Gretna, Gadsden County. Altitude of top of fuller's earth at depth of 158 ft is 107 ft above sea level. | | | | | | | | | | |
| *Depth interval (ft)* | | | | | | | | | | |
| 84 | Francolite cobbles (?), white, claylike; enclosed by sand | | | | | | | | | 10 francolite. |
| 84-90 | Clay, greenish-gray, plastic, sandy | | | 8 | | 2 | Tr. | | | |
| 88 | Thin clay zone, lighter colored than preceding interval | | | 6 | | | | | | 4 opal. |
| 158-162.5 | Fuller's earth, light-gray, sandy, tough | 5 | | 1 | | 4 | | | | |
| 162-162.5 | Dolomite lens, light-yellowish-gray, hard | 2 | | | | | | | 8 | |
| 162.5-175.5 | Fuller's earth, light-gray, tough; contains dolomite lenses in lower part and a soft plastic clay zone in upper part | 4 | | Tr. | | 1 | | | 5 | |
| 174 | Soft plastic clay | 3 | | 3 | | 3 | | | 1 | |
| W3276, 2 miles west of Quincy, Gadsden County. Altitude at top of clay is 258 ft below sea level. | | | | | | | | | | |
| *Depth interval (ft)* | | | | | | | | | | |
| 525 | Clay, greenish-gray, sandy | | | 7 | | 3 | | | | |
| W7472, 2 miles south of Quincy, Gadsden County. Altitude of top of fuller's earth at depth of 118.5 is 137 ft above sea level. | | | | | | | | | | |
| *Depth interval (ft)* | | | | | | | | | | |
| 57.5-62 | Clay, yellowish-gray, plastic: | | | | | | | | | |
| | Sample interval 57-58 | | | 9 | | 1 | | | | |
| | Sample interval 59-60 | | | 9 | | 1 | | | | |
| 69-77 | Clay, yellowish-gray, plastic, sandy: | | | | | | | | | |
| | Sample interval 71-77 | | | 9 | | 1 | Tr. | | | |
| 82-90 | Clay, yellowish-gray, plastic, calcareous, phosphatic: | | | | | | | | | |
| | Sample interval 84-90 | | | 7 | | 3 | Tr. | | | |
| 118.5-122 | Fuller's earth, light-yellowish-gray, sandy and silty; contains angular fragments of clay: | | | | | | | | | |
| | Sample interval 119-122 | 5 | | Tr. | | Tr. | | | 5 | |
| 131-139 | Fuller's earth, light-greenish-gray; contains a few laminae of sand, some of which are calcareous: | | | | | | | | | |
| | Sample interval 131-138 | 8 | | 1 | | 1 | | | | |
| | Sample interval 138-139 | 7 | | 1 | | 2 | | | | |
| W7528, 3 miles south-southwest of Havana, Gadsden County. Altitude of top of clay at depth of 59 is 176 ft above sea level. | | | | | | | | | | |
| *Depth interval (ft)* | | | | | | | | | | |
| 43.5-47 | Clay, yellowish-gray, plastic, sandy | | | 5 | 1 | 4 | | | | |
| 59-69 | Clay, olive-gray, plastic, phosphatic, sandy: | | | | | | | | | |
| | Sample interval 64-69 | | | 6 | | 4 | | | | |
| 72.5-82 | Clay, olive-green, plastic, calcareous in part, somewhat sandy: | | | | | | | | | |
| | Grab sample of clay at 80 | | | 8 | | 2 | | | | |
| | White calcareous nodule out of clay at 80 | | | | | | | 10 | | |
| W6999, on south side of Lake Talquin, Leon County. Altitude of top of clay is 53 ft above sea level. | | | | | | | | | | |
| *Depth interval (ft)* | | | | | | | | | | |
| 62-65 | Fuller's earth, light-gray, tough | 3 | Tr. | 2 | | 1 | | | 4 | |
| W7180, southwest of Lake Iamonia, Leon County. Altitude of top of fuller's earth at depth of 80 is 199 ft above sea level. | | | | | | | | | | |
| *Depth interval (ft)* | | | | | | | | | | |
| 80-85 | Fuller's earth, light-gray, tough | Tr. | | 7 | | 3 | | | | |
| W7181, 2 miles northwest of Bradfordville, Leon County. Altitude of top of fuller's earth at depth of 69 is 180 ft above sea level. | | | | | | | | | | |
| *Depth interval (ft)* | | | | | | | | | | |
| 69-71 | Fuller's earth, light-gray, tough | Tr. | | 9 | | 1 | | | | |

# INDEX

[Italic page numbers indicate major references]





☆ U.S. GOVERNMENT PRINTING OFFICE: 1974—543-585/115