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Geology and Industrial Mineral Resources of the Macon-Gordon Kaolin District, Georgia

by

B.F. Buie[1/], John H. Hetrick[2/], Sam H. Patterson[3/],

and Cathy L. Neeley[3/]

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1/ Florida State University, Tallahassee, Florida

2/ Georgia Geological Survey, Atlanta, Georgia

3/ U.S. Geological Survey, Reston, Virginia

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Abstract

The Macon-Gordon kaolin district is about 80 miles (130 km) southeast of Atlanta, Georgia. It extends across the boundary between, and includes parts of, the Piedmont and Atlantic Coastal Plain physiographic provinces. The rocks in the Piedmont are mainly intensely folded sericite schist and granite gneiss containing irregular masses of amphibolite and feldspathic biotite gneiss and scattered igneous intrusive rocks. Most of the crystalline rocks are thought to be of Paleozoic age, but some of the intrusive rocks may be younger. The crystalline rocks are cut by a major unconformity and are overlain by sedimentary formations ranging in age from Cretaceous to Miocene.

The valuable kaolin deposits occur in the Cretaceous beds, undivided, and in the Huber Formation which is of Paleocene to middle Eocene age. The resources of kaolin in the district are estimated in millions of metric tons as follows: reserves, 100; subeconomic resources, 700 to 900; undiscovered resources, probably 700 to 1,000.

In addition to kaolin, the leading mineral commodity mined in the district, crushed stone and sand are now being produced, and fuller's earth and a minor amount of limestone were formerly produced. The crushed stone is quarried from igneous rocks in the Piedmont province. The sand is washed from the Cretaceous

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1/ Florida State University, Tallahassee, Florida
2/ Georgia Geological Survey, Atlanta, Georgia
3/ U.S. Geological Survey, Reston, Virginia

beds, undivided. The fuller's earth was mined from the Twiggs Clay Member of the Barnwell Formation, and limestone was dug from the Tivola Limestone.

Introduction

The Macon-Gordon district, Georgia, is about 80 miles (130 km) southeast of Atlanta (fig. 1). The district straddles the boundary between and includes parts of, the Atlantic Coastal Plain and the Piedmont physiographic provinces. The mapped area covers approximately 730 square miles (1175 sq km) and includes the southern parts of Baldwin and Jones Counties, the eastern part of Bibb County, most of Twiggs County, the western part of Wilkinson County, and the northern part of Bleckley County. The eastern part of the city of Macon is in the western part of the area mapped, the town of Gordon is in the northeastern part, and Jeffersonville, the Twiggs County seat, is in the southern part of the district. The Ocmulgee River drains the western part of the district, and streams flowing southeastward to the Oconee River drain the central and eastern parts. Agriculture, forestry, and mining are the principal industries. Housing subdivisions occupy considerable areas near Macon, and small farms that are primarily homes of people who work in Macon extend over much of the northern part of the district. The district is served by the Southern Railway, the Seaboard Coastline Railroad, Interstate Highway 16, and many paved highways.

Figure 1 near here.

Purpose of report and authorship responsibility

A principal purpose of this report is to organize and publish appropriate parts of the large amount of information on the geology of the Macon-Gordon kaolin district gathered by the senior author during many years of work in the Georgia

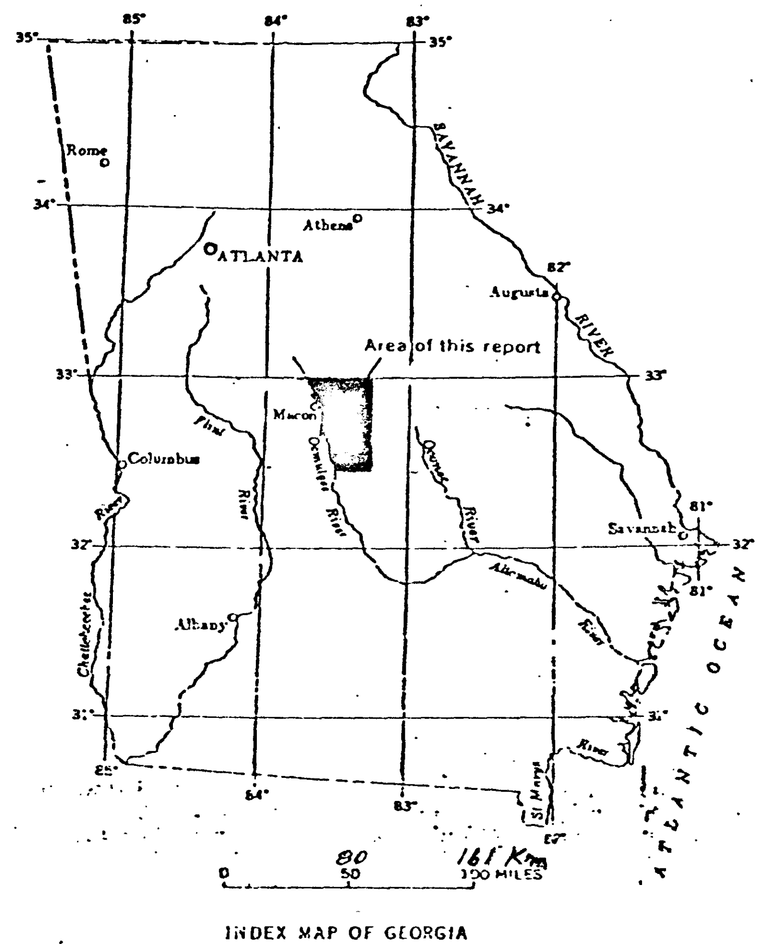

Figure 1. Location of the Macon-Gordon district, Georgia.

kaolin belt. The organization of Buie's work and extensive additional work by Hetrick and Patterson resulted in information useful in planning further development of kaolin and other mineral and water resources of the district. The stratigraphy, extent of rock units shown on the map, and lithologic descriptions are also of value in studies of engineering, environmental, and other problems requiring geologic data.

The division of work and responsibility is as follows: Buie and Patterson did considerable field work and are responsible for the mapping of the Huber Formation and older rocks. Patterson wrote and is solely responsible for the section on kaolin resources. Hetrick also did extensive field work and mapped the rock units younger than the Huber Formation. Neeley compiled the mapping from field sheets, plotted the sections and mining areas, and assisted in writing the report.

All stratigraphic names in this report are used and approved by the Georgia Geological Survey. Two new formations for which definitions have been published recently are the Huber Formation (Buie, 1978) and the Tobacco Road Sand (Huddlestun and Hetrick, 1978), both of which are herein adopted for U.S. Geological Survey usage.

Map preparation and accuracy

Because of the scarcity of outcrops and intense weathering of most rocks in the district, the preparation of the geologic map (pl. 1) required interpretations and projections from control points such as those shown for the top of the Cretaceous beds, undivided,and the top of the Huber Formation (pl. 2). These points (localities where contacts between rock units were recognized and elevations were determined) are most abundant in areas of kaolin mines where exposures are fresh. They are widely scattered in areas away from mines where contacts were observed mainly in road cuts. The plotting of rock units on the topographic base map was done by interpreting structural contour maps prepared for each contact such as the one shown for the top of the Huber Formation (pl. 2). The map is most accurate in areas of abundant mines and is least accurate in areas of weathered rock on ridges and steep slopes and also in a belt along the contact of the crystalline rocks and the overlying sedimentary beds. In a few localities, the authors observed that lithologic characteristics on which the units mapped were identified (pl. 1) have been destroyed by weathering, and beds have been displaced downward by the leaching of lower beds. Among the features destroyed by weathering is the coarse particle size of Cretaceous kaolin, which is one of the criteria for distinguishing deposits of this age from Tertiary ones described in following sections. In other places, beds have crept downslope as the result of mass wasting due mainly to weathering. Because of displacement resulting from weathering, original contacts of some rock units were undoubtedly somewhat higher at some localities than shown on plate 1.

The areas of active and inactive mines shown on the map were plotted from aerial photography flown in 1955 and again in 1972 and from preliminary sheets of the recently published 7 1/2-minute topographic sheets. Several additional mined areas were added during field checking. However, the mining and reclamation in progress in the district make it impossible to illustrate the mine areas accurately without continual revision.

Kaolin deposits are not shown on the geologic map or cross sections (pl. 1) because insufficient information is available to locate them accurately. Kaolin deposits not only are poorly exposed except in mines but they grade laterally and upward into sandy kaolin and kaolinitic sand. The recognition of the extent and boundaries of deposits is therefore exceedingly difficult. Any attempt to show them on a map having the scale of plate 1 (1:62,500 or 1 inch = 1 mile) would require interpretations that would limit the accuracy in plotting deposits and could provide misleading information in litigations concerning property values.

Acknowledgments

Many professional and management personnel aided the authors in many ways during the investigations leading to this report. Among those to whom we wish to express our thanks are John M. Smith, Doral Mills, and Floyd Reynolds, Georgia Kaolin Co.; Fred Gunn, Paul Sennett, Joe H. Mackenzie, Jr., Darwin Soler, and Ed Yaun, Freeport Kaolin Co.; Jack Rogers, E. F. Oxford, Walter Payne, Frank Lazenby, and Ralph B. Hall, J.M. Huber Corp.; Barry Reid and J.F. Lubner, Cyprus Industrial Minerals Corp.; Derek Spry, Anglo American Clays Corp.; James F. Wescott, A.P. Green Refractories Co.; James F. Renaud, General Refractories Co.; and D. C. Hardie, an independent kaolin producer at Gordon. We are grateful to Willis E. Moody and Continental Can Co. for supplying information obtained from a project for kaolin evaluation along Interstate Highway 16 southwest of Jeffersonville. H. H. Morris, former Director of Research and Development, Freeport Kaolin Co., and H. H. Murray, former Vice-President of Georgia Kaolin Co., also aided the authors in several ways. Sam M. Pickering, Jr., helped us in many ways while he was State Geologist of Georgia, and Paul F. Huddlestun, the Stratigrapher of the Georgia Geological Survey, aided in solving correlation problems. Frank W. Stapor and R. Craig Smith served as a crew for plane-table mapping during one field season.

Lithology and stratigraphy

Crystalline rocks

The oldest rocks exposed in the Macon-Gordon kaolin district are a complex group of Paleozoic metamorphic and igneous rocks of the Piedmont province. They consist mainly of complexly folded sericite schist and granite gneiss containing smaller irregular masses of amphibolite and feldspathic biotite gneiss. Small faults and minor displacements along joints are abundant in the crystalline rocks, and major regional faults may extend through this district. However, the authors have observed no topographic expressions or displacements of lithologic units necessary to locate major faults. Intrusions of granitic rocks and diabase dikes are present locally. Some of these intrusive rocks may be of Mesozoic age.

Virtually all the crystalline rocks at the surface are weathered. The most common weathering products are green montmorillonitic saprolite and brown saprolite ricl in illite or hydromica, kaolinite, and mixed-layer clay minerals containing minor quantities of chlorite. The saprolite on granitic rocks consists mainly of kaolinite and halloysite. Quartz is the most abundant mineral in the parent rock that is sufficiently resistant to remain in the saprolite. It commonly is present as veins and stringers. Much of the thoroughly weathered saprolite near the surface grades into a dusky red, dense clayey subsoil in which the textures of the parent rock have been destroyed.

The crystalline rocks are cut by a major unconformity; their upper surface is undulating and inclines seaward (to the southeast). Local undulations along the edge of the overlap of sedimentary rocks have a relief of as much as 150 ft. (46 m). The contact of the crystalline rocks and the overlying sedimentary beds is at altitudes of 425 to 575 ft. (130 to 176 m) along the edge of the overlap and at about 1100 ft. (330 m) below sea level in a dry hole (no oil or gas) near Tarversville in the southwestern part of the district.

Cretaceous beds, undivided

The oldest sedimentary rocks of the Coastal Plain in this district consist of a sequence of Cretaceous beds resting unconformably on the crystalline rocks. These beds form a large wedge-shaped unit that is absent where truncated by erosion updip and is more than 1100 ft. (335 m) thick where penetrated by the dry hole near Tarversville. They are also known to be thicker than 490 ft. (150 m) in the east-central part of the district where a Georgia Kaolin Company well 2.5 miles (4 km) south of Gordon bottomed in Cretaceous sand at this depth. At a mine of J. M. Huber Corporation in Flat Creek in central Twiggs County, near the southwest margin of the district, the top of the Cretaceous is at 365 ft. (112 m) elevation. The top of the pre-Cretaceous rocks is about 500 ft. (153 m) below sea level (Herrick and Vorhis, 1963, figure 20; adjusted for depth to basement in the Tarversville well). Hence, the thickness for the Cretaceous beds in central Twiggs County is probably about 850 ft. (259 m).

The exposures of the Cretaceous beds are restricted to the deeper stream valleys; in the intervening uplands, the beds are blanketed by the overlapping Tertiary formations. The longest exposure belt of these beds is in the valley of the Ocmulgee River, where they extend approximately 12 miles (19 km) downstream from the crystalline rocks to the contact with the Huber Formation.

The Cretaceous beds, undivided, consist chiefly of white to buff, crossbedded, irregular and channel-fill deposits of medium grained to very coarse grained, subrounded to angular quartz sand. A zone of quartz- and hematite-cemented pebbles 2-4 in (5-10 cm) in diameter commonly is present near the base. Interstitial kaolinitic clays and white mica flakes are common in the sand. Large valuable kaolin deposits also occur in this unit. The only fossils known to occur in these undivided beds are plant remains. Pollen in a core sample taken above kaolin in a hole near Myricks Mill was of Late Cretaceous (Maestrichtian) age, and another core sample from nearly 230 ft. (70 m) below the surface in a hole drilled farther south was of definite Cretaceous age (Tschudy and Patterson, 1975).

The term "Cretaceous beds, undivided" is used for these strata because their correlation with Cretaceous formations elsewhere is uncertain. This unit was the lower part of the Tuscaloosa Formation of Late Cretaceous age as formerly used in this region (Cooke, 1943; La Moreaux, 1946a,b; and several other authors). The upper part of that formation is now known to be of Paleocene and Eocene age and has been named the Huber Formation. The redefinition and continued use of Tuscaloosa as a formational name for the Cretaceous beds northeast of the Ocumulgee River is undesirable because of their questionable correlation with strata in southwestern Georgia. In southwestern Georgia, the Tuscaloosa is the lowermost of six Upper Cretaceous formations (Eargle, 1955). Kaolin-bearing Cretaceous beds cropping out in the Macon-Gordon district are believed to be approximately equivalent to the Cusseta Sand, the third formation above the Tuscaloosa Formation in southwestern Georgia (Buie and Fountain, 1967). Some of the beds in the subsurface downdip, where the unit is much thicker, may be equivalent to older Cretaceous formations.

The principal criteria for distinguishing the Cretaceous beds, undivided, from the overlying Huber Formation are: the unconformity between the two units commonly marked by a thin zone of limonite; differences in characteristics of the kaolin (table 1);the relative paucity of dark heavy minerals in the Cretaceous strata; and the differences in the lithologic characteristics of the two units. The unconformity is commonly marked by a pronounced undulating surface at the top of kaolin bodies. Kaolin deposits commonly occupy the higher parts immediately below the undulating unconformity because this clay was more cohesive than associated sand, and was more resistant to erosion preceding the deposition of the Huber Formation. Where kaolin is absent, the unconformity is generally indicated by lithologic differences above and below a channeled contact, but the unconformity may be difficult to recognize locally. The Cretaceous sands generally have fewer sedimentary structures typical of near-shore deposits than does the Huber Formation,

Table 1. Characteristics of kaolins of the Cretaceous beds, undivided, and Huber Formation.

General Characteristics	Kaolin in the Cretaceous beds, undivided	Kaolin in the Huber Formation
Color	white to cream or buff, natural brightness high	mainly white to cream, buff, or gray; commonly has a slight greenish tinge that changes to a faint pinkish tint upon exposure; some deposits are very light gray; natural brightness moderate to low
Fracture or parting	smooth; when dry, breaks easily into friable blocks having sharp angles and smooth flat or subconchoidal faces; commonly called "soft kaolins"	mostly breaks into irregular chunks with rough or hackly fracture; commonly called "hard kaolins"
Tubular structures resembling borings or Bryozoa	absent	common
Pisolitic texture	rare	common in upper parts of deposits
Particle size	generally 65 percent or less <2 micrometers; vermicular crystals and "books" common	generally more than 90 percent <2 micrometers; vermicular crystals scarce
Crystal perfection	generally good	generally poor
TiO_2 content	about 1 percent	about 2 percent
Mineral impurities other than quartz sand	mainly mica, miscellaneous heavy minerals: fine-grained dark minerals are rare or unobservable in hand specimens	very fine grained dark heavy minerals moderately abundant and observable in most hand specimens

and the only fossils of Cretaceous age that have been found are plant remains, including pollen (Tschudy and Patterson, 1975); however, pollen, dinoflagellates, and marine mollusks all occur in the Huber Formation. Another criterion for distinguishing the Cretaceous beds from the Huber Formation is the greater dip of the Cretaceous beds. The difference in dip of the two units is too small to be observed in outcrop; however, where the same stratum can be recognized--in drill cores or by other means--at widely separated sites, the Cretaceous beds can usually be identified by their greater dip. The dip of the Cretaceous beds averages 20 to 25 ft. per mile (3.8 to 4.7 m per km); the dip of the Huber strata averages about 15 ft. per mile (2.7 m per km).

Tertiary formations

Huber Formation

The Huber Formation, like the underlying beds, is a wedge-shaped unit that pinches out updip and increases in thickness downdip. It can be recognized in an exposure on Riggins Mill Road, near Macon, where it is only about 2 ft (0.6 m) thick. The greatest measured thickness is 94 ft (29 m) in a mine of J. M. Huber Corporation on Flat Creek in central Twiggs County. In much of the central part of the district, the Huber Formation overlaps the Cretaceous beds and extends onto the crystalline rocks. Its upper contact is also an unconformity, which marks a distinct change in lithology from the light gray to buff sand, kaolinitic sand, and kaolin of the Huber Formation to the darker gray to green sand, montmorillonitic clay, and limestone of the overlying strata.

The Huber Formation as defined by Buie (1978) includes all the strata between the Cretaceous or older rocks upon which it unconformably rests, and the base of strata of Jacksonian Age (late Eocene). Lithologically, the Huber strata closely resemble the Cretaceous strata, and the distinction between the two sequences of kaolin-bearing strata was not clearly recognized until 1964, when commercial kaolin was found stratigraphically above fossils of Claibornian Age (middle Eocene)(Buie and Fountain, 1967). Subsequently, the Claibornian fossils--small mollusks--have been found at many localities below one or more beds of kaolin near the top of the middle Eocene strata. More recently, Tschudy and Patterson (1975) described pollen of definite Claibornian Age from below the kaolin mined in one of the Evans Clay Company pits northeast of Jeffersonville and pollen of Paleocene age from beds above the unconformity above the Cretaceous kaolin at three places in the valley of Flat Creek. At some localities outside the Macon-Gordon district, as at the type locality of the McBean Formation in eastern Georgia, the downdip strata of Claibornian Age contain marine or estuarian fossils and are readily recognized; however, there they do not contain commercial kaolin. For many years, the kaolin beds of Georgia and South Carolina were believed to occur only in Cretaceous strata. As a result of this misconception, the updip Claibornian and older Tertiary strata were previously mapped as Cretaceous.

Lithologically, the Huber Formation is typical of a nearshore environment of deposition. Channel-fill deposits are abundant, and most of the formation is intricately crossbedded. Ilmenite and other dark heavy minerals are abundant and are concentrated along bedding planes. Lignitic clays, which contain the pollen, occur at many places, usually as single beds or as restricted lenses. Rounded boulders of pisolitic kaolin, some of which are gibbsitic and range in diameter from an inch to more than 6 ft. (a few centimeters to more than 2 m) are present in the upper part of the formation at many places. Many of these boulders are enclosed in sand, and they clearly indicate a high-energy environment of deposition.

At one locality, lignitic clay of Paleocene age contains marine dinoflagellates. These fossils and the megascopic marine fauna of Claibornian Age indicate at least two intervals of marine or brackish-water deposition. Quite possibly others occurred also, as the interval of time represented by the Huber Formation is approximately 20 million years. Apparently, however, during a large part of this time, this region was undergoing erosion, and no deposits were being formed.

Three types of tubular features or borings of animals are found in the Huber Formation. One type found only in kaolin deposits in this formation is a peculiar spaghettilike form. Some of these forms are branching and resemble Bryozoa; others are more like fillings of borings. Most of them are about 0.1 in. (2.5 mm) in diameter, and some are as long as 1.2 in. (3 cm). A second type of tubular feature is present in sand and clayey sand beds in the upper part of the formation. This type is commonly as much as 4 in. (10 cm) long. Most of these features are vertical, but they extend in all directions. Most are preserved only as clayey or slightly cemented sand fillings in unconsolidated sand. The third type consists of fillings of borings that have been called Halymenites in older reports (Eargle, 1955). This type of boring is as much as 2 in. (5 cm) in diameter and is known to extend downward nearly 6 ft. (2 m). The first type is found only in the Huber Formation, but the other two types are found in older and younger beds as well as in the Huber.

Clinchfield Sand

In the Macon-Gordon district, the Clinchfield Sand consists chiefly of fine-grained well-sorted quartz containing a very minor amount of heavy minerals. At scattered localities, the lower part of this formation is mainly a calcareous clayey silt containing a few beds of very poorly sorted fine- to coarse-grained sand, some gravel, and dense limestone beds as much as 2 ft.(0.6 m) thick. All the Clinchfield Sand is calcareous in several of the outcrops observed, and probably this formation was originally limey throughout the Macon-Gordon district. The thickest known outcrop of the Clinchfield in the district is 28 ft. (8.5 m), and in most places, it is 12 to 15 ft. (3.6 to 4.5 m) thick. The characteristic molluscan fossils Crassostrea gigantissima and Pecten danvillensis(?) are common in the lower part, and Periarchus lyelli and Aequipecten spillmani clinchfieldensis are common in the upper part of the Clinchfield Sand. Other fossils in the Clinchfield Sand in this area are listed by Cooke and Shearer (1919, p. 48).

Tivola Limestone [1/]

The Tivola Limestone in the area of this report was referred to as the Tivola Tongue of the Ocala Limestone by Cooke and Shearer (1919, p. 51). These authors interpreted the tongue-shaped unit as an interfingering of the Ocala with the Barnwell Formation, and because of its thin nature, it was included in the Barnwell. In the area of the map, the Tivola Limestone is more common in Bibb and Twiggs Counties, and it is best exposed in the small old limestone quarry and in kaolin mines southwest of Dry Branch and northeast of Jeffersonville.

The Tivola Limestone in this area consists mainly of white, loosely cemented, coquinalike masses of Bryozoa fragments. Pecten and echinoid fossils are abundant locally. The unit is lenticular and the maximum thickness exposed is about 15 ft. (4.5 m), but in most exposures, it is less than 6 ft. (2 m) thick.

1/ Stratigraphic term as used by the Georgia Geological Survey.

Barnwell Formation

The Barnwell Formation in the Macon-Gordon district consists of the Twiggs Clay and Irwinton Sand Members. The usage of the Twiggs Clay Member of this formation follows the usage of Cooke and Shearer (1919, p. 52) who originally proposed the name after exposures near Pikes Peak, Twiggs County, Ga. The name Irwinton Sand Member was first used by La Moreaux (1946a,b)who also recognized the Twiggs Clay Member. La Moreaux also included an unnamed upper sand member in the Barnwell Formation; however, Huddlestun and Hetrick (1978) included this member in a new formation named the Tobacco Road Sand (discussed in a following section).

The Twiggs Clay and the Irwinton Sand Members interfinger, and the contact between them is gradational in places. Lenticular units and thin beds of sand also occur locally in the Twiggs and at some places, the Twiggs clay lenses are present in beds having mainly the lithology of the Irwinton Sand Member.

Twiggs Clay Member

The fresh Twiggs Clay Member observed in deep cuts and drill core consists mainly of pale- and dark-gray clay. The oxidized weathered clay seen in most exposures is greenish gray. The member commonly contains thin laminae of fine-grained sand and silt, and much of the clay is interbedded with sand. Ovoid concretions and thin beds of lithographic limestone, some of which contain marine fossils, occur locally. Large lenticular units of very light weight clay of the fuller's earth type are present at many places. However, most of the member is bedded clay that is somewhat more dense than the fuller's earth. Beds of opal- or cristobalite-cemented sand as much as 2 ft. (0.6 m) thick occur at a few places. Leaves of several species of plants associated with invertebrate fossils were found in the Twiggs at one locality on the old Marion road, Twiggs County (Berry, 1914, p. 129-131; Cooke and Shearer, 1919, p. 54-55). The maximum thickness of the Twiggs Clay Member in the Macon-Gordon district is approximately 150 ft. (46 m).

The Twiggs Clay Member consists mainly of montmorillonite, but minor amounts of kaolinite are present in most of the unit. Kaolinite tends to be most abundant in the lower parts of the member. It is also abundant in the most weathered parts where it apparently formed by the alteration of montmorillonite. The fresh unoxidized clay is generally calcareous.

Irwinton Sand Member

The Irwinton Sand Member of the Barnwell Formation consists mainly of fine- to medium-grained, well-sorted sand containing a few heavy minerals. Laminae and thin beds of pale green to gray clay, which are in lenticular units and interfinger with the Twiggs Clay Member, are present at many places. Much of this clay is mottled with red and reddish-brown stains of iron oxide in weathered outcrops. Many of the medium-grained sand beds have intertidal-type crossbedding. None of the exposed sand in the Macon-Gordon district is calcareous, although farther east, this member typically is calcareous (La Moreaux, 1946b, p. 63). However, a core of the Irwinton Sand Member from a drill hole near Jeffersonville is calcareous. In much of the eastern and southeastern parts of this district, the Irwinton is as much as 50 ft. (15 m) thick, but at many places in the western part, this member is missing and the Barnwell Formation is represented only by the Twiggs.

Tobacco Road Sand, including Sandersville Limestone Member

The Tobacco Road Sand is a newly proposed formational name (Huddlestun and Hetrick, 1978) for a unit of upper Jacksonian strata between the Barnwell Formation and the Hawthorn Formation of Miocene age. The Tobacco Road Sand includes the Sandersville Limestone Member in its lower part in Washington County, Georgia (now reassigned from the top of the Barnwell Formation), and replaces the former unnamed upper sand member of the Barnwell Formation as used by La Moreaux (1946a, b). The type locality is near Agusta, Georgia.

In the Macon-Gordon district, the Tobacco Road Sand consists mainly of medium- to coarse-grained sand, but the upper part in down-dip areas is massive fine-grained sand. Most of the formation is poorly sorted, and locally it is bioturbated and cemented with silica. Small dark heavy minerals are moderately abundant, and oxidation of those containing iron causes most of the sand in weathered outcrops to have a brown or reddish-brown color. A zone of rounded and flattened quartz pebbles is present near the base at many places. The formation locally contains a few small pelecypods and fragments of oyster shells. The Tobacco Road Sand has a maximum thickness of about 25 ft. (7.6 m) in this district.

Hawthorn Formation

Beds above and resting unconformably on the Tobacco Road Sand are thought to be part of the Hawthorn Formation of Miocene age (P. F. Huddlestun, oral commun., 1976). This formational assignment is somewhat tenuous because these beds are very poorly exposed and most of the few outcrops found are thoroughly weathered. The name Hawthorn is used herein because it has been applied to a very large wedge-shaped unit of variable sediments extending from northern Florida across the Coastal Plain of Georgia into South Carolina. The Hawthorn Formation is present only in the downdip (southern) part of the Macon-Gordon district. Its maximum thickness in this district is approximately 200 ft. (60 m).

The Hawthorn Formation consists of very poorly sorted lenticular units of sediments having a wide range of particle size and mineral composition. Most of the formation is probably sand, but gravely, sandy clays are present locally. Much of the fresh part of the formation consists mainly of mixtures of quartz, feldspar, kaolinite, and smectite. The feldspar and montmorillonite or other members of the smectite group are altered by weathering, and typical surface exposures are mainly composed of quartz and kaolin.

Alluvium and residuum

Pliocene(?) and Pleistocene alluvium

Older alluvium that includes some deposits that are probably of Pliocene age is present in a few places. Alluvium consisting of sand, minor gravel, nodules of iron-cemented sand and chert, and a few clay balls form benches on the east side of the Ocmulgee River valley and in the lower Flat Creek valley in the southwestern part of the district. The alluvium is at altitudes of 275 to 280 ft. (84 to 85.5 m) in the Ocmulgee River valley and 300 ft. (92 m) along Flat Creek. These deposits are probably remnants of former extensive valley-floor deposits. Another type of older alluvium is present in isolated patches at altitudes of about 630 ft. (192 m) in the north-central part of the district. This alluvium consists mainly of red, crossbedded, very poorly sorted, medium-grained to very coarse grained sand and sandy clay. It also contains quartz, gravel, and kaolin balls.

Pleistocene and Holocene alluvium

The floors of all the major and many of the minor streams are underlain by Pleistocene and Holocene alluvium. Most of the valleys in the area of crystalline rock are narrow, and the alluvium in them is mainly sand. Stream valleys in the Coastal Plain are broad and swampy. The alluvium in these valleys consists of poorly sorted silt and sand containing minor gravel and clayey muck rich in organic matter. The most extensive deposits of Pleistocene and Holocene alluvium are in the Ocmulgee River valley. This alluvium may be several tens of feet thick.

Residuum

The deposits on the ridges are among the most weathered materials in the Macon-Gordon district; they are difficult to identify and assign to stratigraphic units. Therefore, these weathered deposits are referred to as residuum (QTr) on the geologic map (pl. 1). The residuum is thought to have formed mainly in Quaternary time, but weathering that formed it may have been active throughout the Pliocene and perhaps earlier Tertiary Epochs. The residuum shown on the map is formed mainly from the Hawthorn Formation and younger beds, if any were present in the district. Beds somewhat older than the Hawthorn Formation may also have been weathered to form residuum on isolated ridges in the northern part of the district. Residuum mapped in the southern part of the district is separated from the Hawthorn Formation by a dashed line. This line marks the approximate northern limit of the area in which the Hawthorn Formation, as used in this report, can be recognized. Though much of the area mapped as Hawthorn Formation (Tha) is also covered by residuum, scattered Hawthorn beds can be identified. The last weathered Hawthorn beds found are exposed in road cuts 5 miles (8 km) south of Jeffersonville.

The lithologic characteristics of the residuum vary considerably, Most of it is very dark reddish-brown, unsorted, and nonbedded fine-grained sand to gravel-sized particles. Most residuum near the surface is irregularly mottled; the mottling is caused by the chemical complexing and removal of some of the iron oxide by decaying plant roots. Quartz is the only mineral identifiable with a hand lens, because virtually all grains are coated with and partly cemented by iron oxide. Residuum is so thoroughly weathered that some of the gravel-size quartz is easily crushed by finger pressure. Irregular thin bands of gray gley are present locally.

Another type of residual or lag material was found on uplands north of Commissioners Creek near the north edge of the area mapped. This material consists of an irregularly distributed thin veneer of fluvial cobbles as much as 8 in. (20 cm) in longest dimension. These cobbles, which are not shown on the geologic map, are mentioned only because they may be remnants of high terrace deposits or lag materials remaining after the erosion of a landward facies of one or more of the formations mapped farther south. The regional affinities and age of these cobbles were not identified by the authors; they are noted here only because they are an unsolved problem in the complex history of Coastal Plain sedimentary rocks.

Structure

The dominant structural features in the Macon-Gordon district are the intensely folded and faulted crystalline rocks in the Piedmont province and the very gently dipping strata in the Coastal Plain. The gneisses and schists in the Piedmont are complexly distorted and are characterized by many tight overturned folds and vertical or steeply dipping beds. Small displacements along joints are common, and faults having regional extent may cut across the district. The gentle dip of the Cretaceous and Tertiary beds is seaward, toward the Atlantic Embayment of Georgia (Herrick and Vorhis, 1963, p. 53). The dip of the Cretaceous strata is about 25 ft. per mile (4.7 m per km). The dip of Tertiary strata is about 15 ft. per mile (2.7 m per km).

Joints are abundant in most of the sedimentary rocks, including the kaolin deposits, and small faults have been observed in a few places. One very minor fault was seen in Cretaceous rocks and another, having a maximum displacement of about 5 ft. (1.8 m) was observed in a mine where it cut the Huber Formation but died out upward before reaching the overlying Jacksonian strata. This restriction of the displacement to the Huber Formation indicates that the faulting, or slumping, took place in Claibornian time and that no subsequent movement has taken place along that break.

Slickenside surfaces on partings and fractures are abundant in much of the kaolin and indicate that movement took place. Most slickenside surfaces are small, but some have been observed to extend more than 6 ft. (2 m). Slickensides have no consistent orientation either vertically or horizontally and do not fit into any discernable pattern. Though they indicate movement and displacement, they cannot be considered proof of tectonic disturbance.

The enclosed structural contour of the top of the Huber Formation at 420 ft. (128 m) in the west-central part of the district (pl. 2) appears to represent a structural dome. However, no reversals of dip were observed, and the authors believe this feature is merely a high area on the undulating unconformity between the Huber Formation and the Jacksonian beds. The high area shown by the contours was probably a hill that stood as a promontory in the advancing early Jackson sea.

Economic geology

Kaolin, crushed stone, and sand are produced in the Macon-Gordon district at present; fuller's earth and limestone were formerly produced. All these mineral commodities except crushed stone are present in the sedimentary rocks of the Coastal Plain. The crushed stone is quarried from large masses of granitoid igneous rock in the crystalline rocks of the Piedmont region.

Kaolin

Kaolin is by far the most important mineral commodity produced in the district. The technology of kaolin production, involving mining and beneficiation, is briefly mentioned here. For fuller treatment of this subject and of the geology of the deposits, the reader is referred to: Patterson and Buie (1974) and Patterson and Murray (1975). For additional information on the geology of the kaolin, refer to: Kesler (1963), and Buie (1978).

Kaolin, in general usage, refers to the massive white or light-colored material composed of any one of several clay minerals. All the kaolin produced in the Macon-Gordon district is composed of microscopic crystalline particles of the mineral kaolinite. Chemically, kaolinite is a hydrous aluminum silicate having the formula $Al_4[Si_4O_{10}](OH)_8$, which may also be written $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$. The analysis of pure typical kaolinite by weight percent is:

Al_2O_3	39.50
SiO_2	46.54
H_2O	13.96
	100.00

Most particles of kaolinite are too small to be seen by the unaided eye, but when observed through the scanning electron microscope at magnifications of several thousand diameters, they can be seen to be flat, platy, crystalline units having more or less well-developed hexagonal outlines (figs. 2 and 3).

Figures 2 and 3 near here.

Kaolin mined in the Macon-Gordon district at present consists of 80 percent to 98 percent kaolinite. Quartz sand is the major impurity and all gradations of sand and kaolinite are present. Other impurities consist of small amounts of muscovite, bleached biotite (resembling muscovite), staurolite, ilmenite, anatase, rutile, and various forms of iron oxide or iron sulfide. Highly variable trace

Figure 2. Scanning electron micrographs of Cretaceous kaolin.

a. End view of kaolinite book near center of field (1100 x). Several smaller books show profile view.

b. End view of kaolinite book near center and cross-section view of book in upper right part of field (11000 x). Many plates are hexagonal crystals.

c. End view of a kaolinite book near the center and elongate vermicular book is present near the right margin of the field (5500 x). These large books and the small ones in the lower left part of the field illustrate the wide range in particle size of the kaolin.

a

b

c


10µm
9JAN79 10KV 1100X B72-14
1µm
10JAN79 30KV 11000X B72-14
2µm
9JAN79 10KV 5500X B72-14

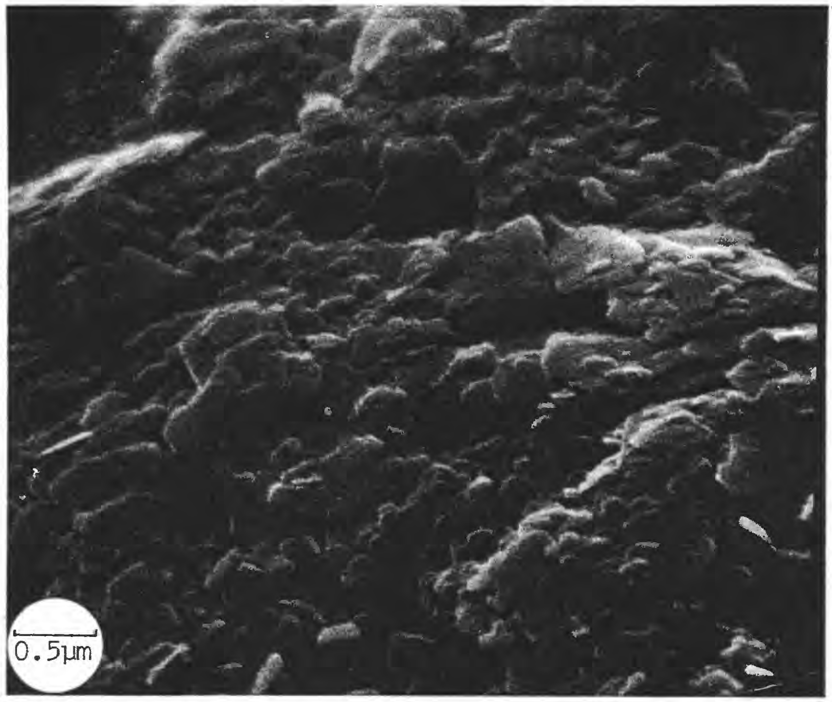

Figure 3. Scanning electron micrograph of Tertiary kaolin (22,000 x).

amounts of zircon, tourmaline, kyanite, and graphite are present in some of the kaolin.

Where the kaolin has been subjected to oxidizing waters, the iron has become oxidized to ferric oxide and the kaolin is likely to be some shade of buff, brown, or red. Where unoxidized, iron is present as the black ferrous oxide or sulfide, and the kaolin is gray or greenish. Gray coloration is also produced by the presence of small amounts of organic material and finely comminuted plant material.

The wet processing of kaolin involves several steps and yields highly refined products. The obvious first step of dispersing the clay in water is done in the blunger (mixing machine) either in the mine or at the plant. The second step is a degritting process, in which the slurry is passed through classifiers to remove coarser nonclay materials. Some of the coarser kaolin particles are also lost in this step. The following steps vary somewhat in different plants, but they involve washing, purification, separation of particle sizes, and grading to fulfill the specifications of special uses or products. In one of the early steps, sulfuric acid is added to the kaolin until it has a pH of about 3; a strong reducing agent, such as a hydrosulfite, is then added and reacts with the iron to form a soluble sulfate that is removable during dewatering. The flocculated slurry is dewatered by centrifuges, rotary vacuum filters, or filter presses. The dewatered kaolin is dried with rotary, spray, or drum driers. Most of it is then ground in a Raymond[1/] (or another type) pulverizing mill. Some of the kaolin is shipped in slurry form(having approximately 70 percent solid content) in tank cars.

1/ The use of trade names in this paper is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

Most plants produce special delaminated grades of kaolin that are particularly suitable for lightweight paper coatings, paint films, and special rubber applications. The delaminated kaolin is produced by splitting apart the larger books or vermicular crystal growths of kaolinite. The resulting individual platelets are thinner and whiter than the larger aggregates. The splitting is done by wet attrition grinding and extrusion processes.

The high-intensity (18 to 22 kilogauss) magnetic separator removes substantial quantities of discolorants that do not respond to conventional methods of chemical leaching. The discolorants in Georgia kaolin are primarily iron-stained, titaniferous, and micaceous minerals (Oder and Price, 1973, p. 75). The principal component of the separator system is a canister filled with a special type steel wool placed within a magnetic field, through which the kaolin slurry is pumped. The magnetic particles remain in the steel wool until the magnet is de-energized. They are then removed by back flushing with a large volume of water under pressure.

Some kaolin is calcined for special products. When heated to 1050°C, kaolin converts to mullite, silica-alumina spinel, and cristobalite. The calcined form is whiter and brighter, has better hiding properties when used in thin filler applications, and is more abrasive.

Uses

Kaolin has many industrial applications, and new uses are still being discovered. It is a unique industrial mineral because it is chemically inert over a relatively wide pH range, is white, has good covering or hiding power when used as a pigment or extender in coated films and filling applications, is soft and nonabrasive, has low conductivity of heat and electricity, and costs less than most materials with which it competes. Some uses of kaolin require very rigid specifications including particle-size distribution, color and brightness, and suspension viscosity; in contrast, other uses require practically no specifications, for example, in cement, where the chemical composition is most important.

The better grades of kaolin make up most of the tonnage sold and have the highest unit value. Many grades of kaolin are specially designed for specific uses such as paper, paint, rubber, plastics (Brooks and Morris, 1973), and ceramics.

Approximately 50 percent of the total kaolin produced in the United States is used in paper products. Kaolin fills interstices of the sheet and coats the surfaces, imparting smoothness, gloss, brightness, opacity, and printability. Color-picture magazines commonly contain as much as 30 percent kaolin. The rubber industry uses significant quantities of kaolin as filler or extender in both natural and synthetic rubber. The so-called "hard kaolins" improve such properties as strength, abrasion resistance, and rigidity of rubber used in footwear and cable covers. The "soft kaolins" are used to improve abrasion resistance and to lower the elasticity of floor tile and soft rubber goods. Historically, kaolin was first used in ceramics, and part of the kaolin produced is sold for making fine chinaware, pottery, stoneware, ceramic tile, and other ceramic products. Appreciable tonnages of kaolin are also produced for use in making firebrick and other refractory products. Kaolin has more than 25 other uses, including the manufacture of chemicals, catalysts, cement, medicines, adhesives, cosmetics, detergents, fertilizers, sizing compounds, linoleum, and textiles.

Industry

The Macon-Gordon kaolin district has a long history of mining and continues to be the leading kaolin producing center in Georgia. Four companies, J. M. Huber Clay Co., Huber; Georgia Kaolin Co., Dry Branch; Freeport Kaolin Co., Gordon; and Nord Resources Corporation, Jeffersonville, operate mines and plants in the district and produce white kaolin for use in paper, rubber, paint, plastics, and other uses. General Refractories Co. mines kaolin and calcines it at Stevens Pottery for use in refractories. Companies mining kaolin in the district and processing it elsewhere include A. P. Green Refractories Co., Macon;

Anglo American Clays Co., Sandersville; Evans Clay Co., Irwinton; and M. and M. Clays, Inc., McIntyre. The Hardie Clay Company, Gordon, and Sam Hall and Sons, Inc., Macon, mine kaolin mainly for markets outside the district. Inactive clay mines in the district include one a short distance north of the Gordon city limits; it was formerly operated by Harbison Walker Refractories Company.

Occurrence

Kaolin is present in two geologic units in the stratigraphic section: 1) in the Cretaceous beds, undivided (shown as "Ku" on pl. 1); and 2) in the Huber Formation (Th) of Tertiary age. Beds of kaolin, sandy kaolin, and kaolinitic sand are present at many places in the Cretaceous beds and Huber Formation. They are rarely sharply delimited but are generally gradational laterally in all directions. Economic factors largely determine what constitutes a minable or unminable body. The bottom of a kaolin bed commonly terminates against an underlying bed of sand. Upward, the bed of kaolin may grade into sand or, more commonly, may terminate sharply against an unconformity.

Thicknesses of minable beds in the Cretaceous rarely exceed 30 ft. (9 m), and more commonly are 10 to 20 ft. (3-6 m). Thicknesses of minable beds of kaolin in the Huber Formation generally are less than 20 ft. (6 m), but at the Evans Mine 5.5 miles (8.8 km) northeast of Jeffersonville, the kaolin mined is reported to have been 60 ft. (18 m) thick. The Cretaceous and Huber kaolins have different characteristics, as described in table 1.

Mining methods

All mining in the district is done by open-pit methods. Thickness of overburden removed now exceeds 100 ft. (34 m). Pans (earth moving scrapers), bulldozers, and draglines are used in stripping. In most mines, the kaolin is removed by dragline from a single bed of either Cretaceous or Tertiary age.

In a few mines where Tertiary kaolin is above Cretaceous kaolin, clay is dug from both beds. The output of some mines is hauled by trucks to the plant. In other mines, the clay is made into a slurry and the thick fluid is pumped by pipeline.

Water must be pumped from most mines to permit access to the clay, and problems of water removal are increasing. As mining progresses downdip to the southeast, the overburden thickens and the quantities of water that must be pumped increase. In the valley of Flat Creek, artesian water rose to an altitude of about 310 ft. (94 m), 20 to 40 ft. (6 to 12 m) below the surface, and a very large volume of water had to be continuously pumped in order to lower the water table sufficiently to permit mining. Similar water conditions are to be expected in downdip areas where the kaolin is below the potentiometric surface of an artesian aquifer.

Resources

The Macon-Gordon district contains large resources of kaolin, and the estimates of their size expressed in following sections are based on many odds and ends of information and geologic interpretations. The reserve estimates are particularly problemmatical because only piecemeal information is available on the kaolin owned by industry and areas favorable for deposits that haven't been explored by core drilling. Kaolin companies rightfully regard their reserve calculations as privileged information, and therefore reserve estimates are based mainly on judgements of such things as density of mines in areas known to contain kaolin, quantities of reserves required to amortize plants, estimates of past production, geologic projections, etc. The resource classification used in this report is modified from the principles outlined by the U.S. Bureau of Mines and the U. S. Geological Survey (1976). All estimates are for kaolin in the ground, and loss in mining is not considered. The estimates are for kaolin on a dry basis and are calculated as having the sand impurities removed.

Definitions

Reserves.--Kaolin reserves are defined as clay present under overburden no more than 200 ft. (61 m) thick that can be mined and processed by methods now in use. The kaolin reserves contain no more than 20 percent sand impurities. In addition to overburden having to be less than 200 ft. (61 m) thick, the overburden:clay ratio must be less than 10:1 for profitable mining; the ratio in many mines is less than 5 to 1.

Subeconomic resources.--Resources in the subeconomic category consist of kaolin that is not profitable to mine and market by present methods and technology. As used in this report, subeconomic kaolin contains no more than 40 percent sand impurities and has the same overburden restrictions as the reserves. Much of the subeconomic kaolin actually contains considerably less than 10 percent sand impurities, but lacks essential properties such as brightness and low viscosity required for present processing technology and markets.

Undiscovered resources.--The undiscovered kaolin is in deposits that remain to be found. The maximum overburden limitations applied to this category of deposits is 250 ft. (76 m). The other restrictions on kaolin in this category are the same as those for subeconomic resources.

Location

The kaolin resources in the Macon-Gordon district are widely scattered through the areas mapped as Cretaceous beds, undivided, and the Huber Formation (pl. 1). The reserves are mainly in the broad, extensively mined belt extending across the district on a southwest-northeast trend and downdip (southeastward) from this belt. Subeconomic kaolin resources are associated with the reserves, and large deposits also are present in regions northwest and southeast of the reserve belt.

The most favorable areas for undiscovered deposits are in a belt about 6 miles (9.7 km) wide having its southeastern boundary approximately along a line extending from the lower Savage Creek Valley in the southern part of the district northeastward through the Porter Creek Valley. This belt includes, in addition to the Savage Creek Valley, all the lower Flat Creek valley below where Buck Branch joins the main creek. It also includes the drainages of the upper tributaries of Porter Creek valley and several small tributaries flowing northward into Big Sandy Creek. Another large area that is favorable for finding more Tertiary ("hard") kaolin is north and northeast of Gordon.

Estimates

The resources of kaolin in the Macon-Gordon district are estimated in millions of metric tons as follows: reserves, more than 100; subeconomic resources, 700 to 900; and undiscovered resources, probably at least 700 to 1,000. The total kaolin resources are probably 1,500 to 2,000.

Though the total estimated kaolin resources of 1.5 to 2 billion metric tons in the Macon-Gordon district seems like an enormous figure, much of this kaolin has very little value under present economic conditions. The subeconomic deposits are considered not minable today, and undiscovered deposits certainly cannot be mined now. The costs of pumping water from mines is also likely to hinder the development of many deposits that are to be found in several areas outlined as favorable for the discovery of more deposits. Large tracts in these areas are in low terrain, and much of the kaolin is likely to be found where artesian ground water is present.

Crushed stone

Considerable tonnages of crushed stone for concrete aggregate, other highway materials, and miscellaneous construction uses are being produced in the

Macon-Gordon district from granitic rocks by two companies. The Martin Marietta Corp. operates the Ruby quarry, and the Hitchcock Corp. operates the Postell quarry. Both quarries are in the crystalline rocks near the edge of the sedimentary overlap. The location of these quarries is controlled by the presence of granitic rocks and the absence of high-quality aggregate materials in the extensive Coastal Plain to the southeast. The quarries are in large masses of granitic rocks, and resources are adequate for several decades.

Fuller's earth

The General Reduction Company mined fuller's earth from the Twiggs Clay Member of the Barnwell Formation for many years in the Pikes Peak neighborhood which is approximately 1 mile (1.6 km) east-northeast of Stone Creek Church. Absorbent granules used mainly for floor sweep and animal litter were the principal products. The clay was processed in a plant in the southern part of the city of Macon. This plant closed in the mid-1970's because of dust and other environmental problems.

The properties making part of the Twiggs Clay Member valuable for fuller's earth are mainly mineral composition and high porosity. The clay suitable for fuller's earth consists mainly of montmorillonite and poorly ordered low-temperature cristobalite that is called opal by some authors. The clay is very light weight and granules made from it are highly absorbent and weigh as little as 30 pounds per cubic foot (47.5 kg/m^3). For additional information about absorbent granules and other fuller's earth products, the reader is referred to a report by Patterson and Murray (1975).

Although the Twiggs Clay Member varies considerably in compositon, very large resources suitable for making absorbent granules and other fuller's earth products are present in the Macon-Gordon district. The Twiggs in the Pikes Peak neighborhood is about 100 ft. (30.5 m) thick and consists of two beds of fuller's earth separated by a unit of sand and clay. The lower bed, which is more than 30 ft. (9 m) thick, was mined near the railroad many years ago. The upper bed which is 25 to 30 ft. (7.7 to 9.2 m) thick was the source of the last production. The fuller's earth extends for more than 2 square miles (5.2 sq km) in the vicinity of the old mines. The Twiggs Clay Member is also known to be present in many parts of the district shown as lower Jacksonian beds, undivided, on plate 1 and to be more than 60 ft. (18.3 m) thick at several places. Much of this clay contains too much kaolinite and nonclay silt in addition to the essential minerals montmorillonite and cristobalite to be of value as fuller's earth. However, a well-planned exploration program could no doubt discover several million tons of clay as good as or better than that formerly mined.

Limestone

Small bodies of limestone in the Tivola Limestone and the Twiggs Clay Member of the Barnwell Formation are present at several places in the west-central and southern parts of the Macon-Gordon district. Small diggings for local use were found in a few places. The largest workings are approximately 1 mile (1.6 km) east of Huber where a few thousand tons were produced probably before the World War II period. This limestone is about 15 ft. (4.5 m) thick and consists mainly of weakly cemented fragments of Bryozoa. According to La Moreaux (1946b, p. 56), two samples of limestone in this vicinity contained an average of 92 percent calcium carbonate.

Resources of limestone in the Macon-Gordon district are inadequate for even a small quarry. However, the deposits in the vicinity of the old workings might be suitable for local use and possibly could be used for liming soil in mine reclamation. This limestone is so weakly cemented that it crumbles readily and might be spread without crushing.

Sand

Sand for use in concrete, mortar, and miscellaneous construction uses is produced by three companies in the Macon-Gordon district, although other companies have been active in the past. The active companies are the M and W Sand Company having pits in the valley of Gaylor Creek north of Gordon; the Cornell Young Sand Company having pits along Riggins Mill road; and Sand Suppliers, Inc., operating in the Swift Creek valley near Macon. One of the inactive pits is in the Turkey Creek valley north of Gordon. The sand is produced by washing down banks by hydraulic methods, which are effective in removing the clay impurities, and by pumping the loose sand to nearby screening and drying facilities. Several old small sand workings near Macon have been reclaimed and are now areas of housing subdivisions or other land use.

The sand worked in the active pits and most of that produced in other workings in the past is from the Cretaceous beds, undivided. Resources of sand in these beds in the district are more than adequate to fulfill the demands for many decades, and, in addition, younger formations contain very large quantities of sand. Probably more than one million cubic yards of sand is moved annually in stripping kaolin deposits. To date, kaolin companies haven't found it profitable to process any of the sand moved except for mine road construction and as backfill. Very large tonnages of essentially pure quartz sand could be recovered from the stripping operations, and adequate supplies of water for washing are available in mined-out pits.

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