Ball Clay and Bentonite Deposits of the Central and Western Gulf of Mexico Coastal Plain, United States

GEOLOGICAL SURVEY BULLETIN 1558-C

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By JOHN W. HOSTERMAN

CONTRIBUTIONS TO THE GEOLOGY OF MINERAL DEPOSITS

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Geology and geologic setting of ball clay and bentonite deposits

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BALL CLAY AND BENTONITE DEPOSITS OF THE CENTRAL AND WESTERN GULF OF MEXICO COASTAL PLAIN, UNITED STATES

By John W. Hosterman

ABSTRACT

The Gulf of Mexico Coastal Plain produces approximately 85 percent of the ball clay used in the United States. The best commercial-grade clay deposits are composed of poorly crystalline kaolinite and small amounts of *Md* illite and (or) smectite. Sand and silt and iron oxide minerals are virtually absent, but quartz is present in the clay-size fraction. The best grade ball clays are found as lenses limited to the Wilcox Group (Paleocene and lower Eocene) and Claiborne Group (middle Eocene). Reserves of ball clay are sufficient for the present, but because of the lenticular nature of the clay bodies, close-spaced drilling, detailed sampling, mineralogic analyses, and ceramic testing are needed to prove future reserves.

Approximately 11 percent of the total bentonite produced in the United States comes from the Gulf Coast region. The commerical-grade bentonites are composed primarily of smectite with little or no *Md* illite and kaolinite. The nonclay impurities are quartz, feldspar, muscovite, biotite, calcite, dolomite, gypsum, and heulandite. Commerical bentonites occur in the Upper Cretaceous formations in Alabama and Mississippi, in Paleocene formations in Mississippi and Tennessee, and in Eocene and Miocene formations in Texas. The demand for low-swelling bentonite of the Gulf Coastal Plain has not increased along with the demand for swelling bentonite; therefore the reserves are adequate.

INTRODUCTION

The Gulf of Mexico Coastal Plain is part of a continuous plain thousands of kilometers long that extends from southern Mexico to New Jersey bordering the Gulf of Mexico and the Atlantic Ocean. This report is limited to that part of the Gulf Coastal Plain, including the Mississippi Embayment, in the States of Alabama, Mississippi, western Tennessee, western Kentucky, Arkansas, Louisiana, and eastern Texas. Geologically, the Gulf Coastal Plain is made up of sedimentary rock units that dip gently southward so that successively younger formations crop out toward the Gulf. The landward margin of the Gulf Coastal Plain consists, in part, of rocks of Late Cretaceous age composed mostly of impure chalky limestones, marls, and shales. Toward the Gulf, younger formations of Tertiary age are exposed. They are composed mostly of sandstones, shales, and clays, but also include lenticular bodies of lignite, canneloid coal, and subbituminous coal and accumulations of volcanic ash and volcanic tuff. The bentonite deposits found throughout the Gulf Coastal Plain were derived as an alteration product of the volcanic ash. The ball clay deposits were formed by sedimentary accumulations of material transported by water.

STRATIGRAPHIC OUTLINE

The bentonite and ball clay deposits of the Gulf Coastal Plain are found in formations ranging in age from Late Cretaceous to middle Tertiary (pl. 1). The Upper Cretaceous units occur in two belts at the surface. One belt, the western Gulf Coastal Plain, extends from the Rio Grande in southern Texas to southwestern Arkansas. The other belt, in the eastern Gulf Coastal Plain, extends from the northern end of the Mississippi Embayment, across western Tennessee, northeastern Mississippi, central Alabama, and into Georgia. Rocks of Paleocene age overlie the Upper Cretaceous rocks of both belts and, in part of Arkansas and of Missouri where the Upper Cretaceous rocks are not exposed, they overlie older rocks. The overlying Eocene formations occupy the largest area of the Gulf Coastal Plain from southern Texas, across northern Louisiana, eastern Arkansas, southeastern Missouri, western Kentucky, western Tennessee, Mississippi, southern Alabama, and to southern Georgia. Rocks of Oligocene age crop out in a narrow belt across central Louisiana, Mississippi, and southern Alabama. Miocene formations are found in a belt that parallels the coast from Texas to Georgia. In Texas, where Oligocene units are not positively identified, Miocene units are shown overlying Eocene units (pl. 1). A generalized stratigraphic outline of the sedimentary units referred to in this report is shown in figure 1.

UPPER CRETACEOUS SERIES

The Upper Cretaceous Series, known as the Gulf Series throughout the Gulf Coastal Plain, lies unconformably on Lower Cretaceous, Jurassic, or older rocks. The Gulf Series has been subdivided (Murray, 1961, p. 333) into five Stages. They are:

Navarroan
Tayloran

Austinian
Eagle Fordian
Woodbinian

In the eastern part of the Gulf Coastal Plain of Alabama, Mississippi, and Tennessee, the Tuscaloosa Group Formation is composed of upper and lower sand and gravel units and a middle marine shale unit. In the western part of the Gulf Coastal Plain of Texas, Oklahoma, and Arkansas, the Woodbine Formation is predominantly sand, and, in the lower part, tuffaceous material and appreciable amounts of gravel.

The Eagle Fordian Stage includes the Eagle Ford Formation, the upper part of the Tuscaloosa, and the lower part of the Eutaw Formation. In the eastern part of the Gulf Coast, the Eutaw is composed of sands and shales that are finer grained and more calcareous seaward. The Eagle Ford in the western Gulf Coast is characterized by black shale and thin beds of bentonite, flaggy limestone, chalky limestone, and some clay.

The Austinian Stage contains the upper part of the Eutaw Formation, basal beds of the Selma Group, the Tokio Formation, and the Brownstown Marl. In Mississippi and Tennessee, the Eutaw is typically sand and some interbedded shale. Glauconite, fossils, and calcareous materials are very common. The Mooreville Chalk (Selma Group) overlies the Eutaw. In the western part of the Gulf Coast area, the Tokio consists mostly of sands and shales containing volcanic materials. It is overlain by calcareous shales known as the Brownstown Marl.

The Tayloran stage includes the middle part of the Selma Group in Alabama and Mississippi, the Coffee Sand in Kentucky, Tennessee, and Mississippi, the Ozan Formation and Annona Chalk, and the Marlbrook Marl in Arkansas; and the Ozan Formation, Wolfe City Sand, Pecan Gap Chalk, and Marlbrook Marl in eastern Texas. The Demopolis Chalk (Selma Group) is predominantly a calcareous-argillaceous chalk facies. The Marlbrook is composed of brown or gray glauconitic marl and chalky or limy shale. The Annona and Pecan Gap consist mainly of chalk. The Ozan contains chalk, limy shales, marls, and calcareous sands.

The Navarroan Stage is composed of the upper part of the Selma Group in Alabama and Mississippi; the McNairy and Owl Creek Formations in Tennessee and the McNairy Formation in Kentucky; the Saratoga Chalk, the Nacatoch Sand, and the Arkadelphia Marl in Arkansas; and the Neylandville Marl and Navarro Formation in Texas. The Ripley and Owl Creek Formations, the Prairie Bluff Chalk and Providence Sand, varieties of lithologic types, form the upper part of the Selma Group. Both the McNairy and Owl Creek are predominantly sands with subordinate amounts of clay. The Saratoga, Nacatoch, and Arkadelphia are composed of glauconitic chalks, shales, marls, and calcareous sands. The Navarro Group contains marls, chalks, shales, and sands.

EPOCH	STAGE	TEXAS	LOUISIANA	ARKANSAS	KENTUCKY	TENNESSEE	MISSISSIPPI	ALABAMA
MIOCENE		Hemming Formation Catahoula Formation	Hemming Formation Catahoula Formation				Catahoula Formation	Catahoula Formation
OLIGOCENE	VICKSBURGIAN	(Subsurface)	Vicksburg Formation				Vicksburg Group	Vicksburg Group
EOCENE	JACKSONIAN	Jackson Group: Whitsett Formation Manning Formation Wellborn Formation Caddell Formation Moodys Branch Formation	Jackson Group: Yazoo Formation Moodys Branch Formation	Jackson Formation	Jackson Formation		Jackson Group: Yazoo Formation Moodys Branch Formation	Jackson Group: Yazoo Formation Ocala Formation Moodys Branch Formation
EOCENE	CLAIBORNIAN	Claiborne Group: Yegua Formation Cook Mountain Formation Sparta Sand Weches Formation Queen City Sand Reklaw Formation Carrizo Sand	Claiborne Group: Cockfield Formation Cook Mountain Formation Sparta Sand Cane River Formation Carrizo Sand	Claiborne Group: Cockfield Formation Cook Mountain Formation Sparta Sand Cane River Formation Carrizo Sand	Claiborne Formation	Cockfield Formation Claiborne Formation	Claiborne Group: Cockfield Formation Cook Mountain Formation Sparta Sand Zilpha Clay Winona Sand Tallahatta Formation	Claiborne Group: Cockfield Formation Gosport Sand Lisbon Formation Tallahatta Formation
EOCENE / PALEOCENE	SABINIAN	Wilcox Formation	Wilcox Group	Wilcox Group	Wilcox Formation	Wilcox Group	Hatchetigbee Formation Tuscahoma Formation Nanafalia Formation	Hatchetigbee Formation Tuscahoma Formation Nanafalia Formation
PALEOCENE	MIDWAYAN	Midway Group: Wills Point Formation Kincaid Formation	Midway Group: Porters Creek Clay	Midway Group: Porters Creek Clay Clayton Formation	Porters Creek Clay Clayton Formation	Midway Group: Old Breastworks Formation Porters Creek Clay Clayton Formation	Midway Group: Naheola Formation Porters Creek Clay Clayton Formation	Midway Group: Naheola Formation Porters Creek Clay Clayton Formation
LATE CRETACEOUS	NAVARROAN	Navarro Group: Kemp Clay Corsicana Marl Nacatoch Sand Neylandville Marl	(Subsurface)	Arkadelphia Marl Nacatoch Sand Saratoga Chalk	Mc Nairy Formation	Owl Creek Formation Mc Nairy Formation	Selma Group: Prairie Bluff Chalk Owl Creek Formation Ripley Formation	Selma Group: Providence Sand Prairie Bluff Chalk Ripley Formation
LATE CRETACEOUS	TAYLORAN	Marlbrook Marl Pecan Gap Chalk Wolfe City Sand Ozan Formation		Marlbrook Marl Annona Chalk Ozan Formation	Coffee Sand	Demopolis Formation Coffee Sand	Demopolis Chalk Coffee Sand	Demopolis Chalk
LATE CRETACEOUS	AUSTINIAN	Brownstone Marl Tokio Formation		Brownstone Marl Tokio Formation			Mooreville Chalk	Mooreville Chalk
LATE CRETACEOUS	EAGLEFORDIAN	Eagleford Formation				Eutaw Formation	Eutaw Formation	Eutaw Formation
LATE CRETACEOUS	WOODBINIAN	Woodbine Formation		Woodbine Formation	Tuscaloosa Formation	Tuscaloosa Formation	Tuscaloosa Formation	Tuscaloosa Formation

FIGURE 1.—Stratigraphic chart showing many formations and groups of formations of the central and western Gulf of Mexico Coastal Plain. Geologic units from which ball clay has been mined are shown by [pattern]. Geologic units from which bentonite has been mined are shown by [pattern]. (from Bicker, 1970; Clarke, 1970; Dietrich and Lonsdale, 1958; Fisher, 1965; Lusk, 1956; Maxwell, 1962; Murray, 1961; Vestal, 1943; and Vestal, 1956).

TERTIARY SYSTEM

The Tertiary System is subdivided into the following series and stages. They are:

- Pliocene
- Miocene
- Oligocene
  - Vicksburgian
- Eocene
  - Jacksonian
  - Clairbornian
  - Sabinian
- Paleocene
  - Midwayan

The Pliocene Series is not discussed in this report because no clay deposits of this age were ever discovered and mined in the Gulf Coastal Plain.

The Midwayan Stage (Paleocene) is a time-rock unit that contains sedimentary rocks of the Clayton Formation, Porters Creek Clay, and Naheola Formation. The Clayton is a glauconitic, massive limestone with calcareous sand at the base. The Porters Creek consists of dark gray, micaceous, slightly sandy clay. The Naheola has a lower carbonaceous, micaceous sand, silt, and clay member and an upper glauconitic sand and minor amounts of shale. In Texas, the Clayton equivalent is the Kincaid Formation and the Porters Creek equivalent is the Wills Point Formation.

The Sabinian Stage (upper Paleocene and Eocene) is the Wilcox Group, which contains predominantly lignitic to carbonaceous, partly glauconitic sandy clay. The more continental and coarse-grained material is found northward in the Mississippi Embayment proper and fine-grained more calcareous material is found toward the Gulf. In Alabama and Mississippi, the Wilcox is divided into three formations—Nanafalia, Tuscahoma, and Hatchetigbee.

The Clairbornian Stage (Eocene) includes some of the most famous fossiliferous rocks in the world. In Alabama, the Clairborne Group is divided into the Tallahatta Formation, the Lisbon Formation, Gosport Sand, and Cockfield Formation. In Mississippi, Louisiana, and Texas, the group is divided into Cockfield or Yegua Formation, Cook Mountain Formation, Sparta Formation, Zilpha Clay, Cane River or Weches Formation, Winona or Queen City Sand, Tallahatta or Reklaw Formations, and Carrizo Sand. The Lisbon Formation contains clay, marl, and calcareous sand, and the Tallahatta Formation is predominantly an indurated silty claystone. The Cockfield or Yegua Formation and the Sparta Formation contain carbonaceous sand, silt, and clay. The Cook Mountain Formation is composed of glauconitic sands, clay, and marl, and the Weches Formation contains carbonaceous shale and silt and glauconitic clay. The Queen City Formation consists of sand and carbonaceous clay, and the Reklaw

Formation contains a basal glauconitic sand and an upper carbonaceous shale.

The Jacksonian Stage (Eocene) is calcareous in the eastern part, clayey in the central part, and sandy in the western part of the Gulf Coastal Plain. The Ocala limestone in Alabama and Mississippi interfingers with and is replaced by the Yazoo Formation and the calcareous and glauconitic sands and clays of the Moodys Branch Formation. In eastern and central Texas, the Jackson Group is composed of sand and clay beds that contain appreciable amounts of volcanic material. The Whitsett Formation is a cross-bedded sand interbedded with bentonite. The Wellborn Sandstone and Manning Formation contain sands and carbonaceous to lignitic silts and clays. The Caddell Formation is composed of glauconitic silts and clays. The Moodys Branch is mostly glauconitic sand and calcareous silt.

The Vicksburgian Stage (Oligocene) is found in Alabama, Mississippi, and Louisiana. The Vicksburg Group, in the eastern part of the Gulf Coastal Plain, is composed of dark calcareous clays, silts, crystalline limestone, marl, and glauconitic calcareous sand. In Louisiana, where the Vicksburg is a formation, the calcareous facies is replaced by dark carbonaceous clay with local glauconitic marl and sands. The Vicksburg Formation is not recognized as a discrete formation in eastern Texas.

The Catahoula and Fleming Formations have been recognized as Oligocene and Miocene in age. The Catahoula is composed predominantly of sand with some clay and volcanic material. The overlying Fleming is found in the western part of the Gulf Coastal Plain. It contains calcareous clays, some silt and sand, and some bentonite.

MINERALOGIC ANALYSIS METHODS

All samples were analyzed for mineralogic composition on a standard X-ray diffractometer using copper ($CuK\alpha_1$) radiation in conjunction with the following optical arrangements; a 1.0° divergence slit, a medium resolution soller slit, a 0.1° receiving slit, a graphite crystal for monochromatic radiation, and a 5° "take-off" angle. The goniometer was run at a speed of 1° 2θ per minute, and the chart recorder was driven at a speed of 12 inches per hour, so that the X-ray diffraction trace was recorded at a rate of 5° 2θ per inch. The X-ray diffraction trace was used to identify and determine the relative abundances of clay minerals by means of the method described by Schultz (1960). An electronic planimeter was used to carefully measure selected basal peak areas on the X-ray diffraction traces to obtain the proportions of individual clay minerals.

Each sample was ground with alcohol in a tungsten-carbide ball mill for 15–20 minutes. A 0.5 g portion of the ground material was pressed into a wafer 29 mm in diameter. This wafer was used to determine the wholerock mineralogy by X-ray diffraction. Approximately 20 g of the ground material was dispersed in deionized water. An ultrasonic horn was used to disperse the sample. The $<2\ \mu m$ fraction, obtained by settling for a given time and depth, was siphoned off and placed on a porous ceramic tile; the vacuum technique described by Kinter and Diamond (1956) was used for this procedure.

The clay minerals in bentonite and ball clay deposits of the Gulf Coastal Plain are smectite, illite, illite-smectite mixed-layer clay, and kaolinite. The relative amounts, expressed as a ratio because of low accuracy, of clay minerals for each sample were calculated by means of the following techniques. The areas beneath the peaks on the X-ray diffraction traces at 10 A ($8.8°\ 2\theta$) and 7 A ($12.5°\ 2\theta$) were measured with a planimeter. Proportions of smectite, illite, and illite-smectite mixed-layer clay were calculated from the changes in the area of the 10 A peak between the untreated sample, ethylene glycol saturated sample, and the sample heated to 350 °C. The proportion of kaolinite is calculated from the 7 A peak area, which is not effected by the various treatments.

Smectite (montmorillonite), the predominant clay mineral in bentonite, consists of two silica tetrahedral sheets, one alumina octahedral sheet, and space for interlayer water and an exchangeable cation. The theoretical formula of this mineral is considered to be

$$(OH)_4\ Si_8\ (Al_{3.34}\ \underset{\displaystyle \overset{\downarrow}{Ca_{0.66}}\ nH_2O}{Mg_{0.66}})\ O_{20}$$

The arrow indicates that because there is a charge deficiency, it must be satisfied by an exchangeable ion in the interlayer space. Calcium is the dominant exchangeable ion in southern bentonites. Smectite is recognized on the X-ray diffraction pattern by its very strong basal (001) peak at about 14 A which expands to about 17 A when saturated with ethylene glycol and collapses to 10 A when heated to 350 °C for 30 minutes.

Kaolinite is the predominant clay mineral in most ball clay deposits. It is composed of one silica tetrahedral sheet and one alumina octahedral sheet. The structural formula of kaolinite is $(OH)_8\ Si_4Al_4O_{10}$, and its theoretical composition is 39.50 percent Al_2O_3, 46.54 percent SiO_2, and 13.96 percent H_2O. Kaolinite is recognized on the X-ray diffraction patterns by its strong basal (001) peak at 7 A and its moderate basal (002) peak at 3.5 A. Kaolinite is not affected by ethylene glycol saturation or by heating to 350 °C for 30 minutes. Heating kaolinite to about 550 °C changes its crystalline form; however, the exact temperature at which the change takes place is dependent upon grain size and degree of crystallinity. Kaolinite is more immune to attack by warm dilute acids than are most clay minerals; however, dissolution rate also varies considerably by grain size and degree of crystallinity.

Illite is a minor constituent in both the ball clays and some of the bentonites. The well crystalline (*2M*) polymorph of illite has an approximate formula of $(OH)_4K_2(Si_6Al_2)$ $(Mg\ Fe)_6$ O_{20}. However, because the illite in these deposits is the poorly crystalline (*Md*) variety, some of the potassium, magnesium, and iron is missing. Illite is recognized on the X-ray diffraction patterns by its strong basal (001) peak at 10 A, a weak basal (002) peak at 5 A, and a strong basal (003) peak at 3.3 A. The *Md* polymorph is identified by its lack of prism reflections and broad basal peaks. Only the material at the 10 A position when treated with ethylene glycol is considered to be illite.

BALL CLAY DEPOSITS

The term "ball clay" originated from an early English mining practice of rolling the highly plastic clay into balls weighing 30–50 pounds. Ball clay is used primarily in the ceramic industry for making such items as pottery, dinnerware, stoneware, and sanitary ware. Ball clay is composed of poorly crystalline kaolinite with small amounts of (*Md*) illite, and (or) smectite. Quartz sand or silt and iron oxide minerals are virtually absent from the best-grade ball clays, but carbonaceous material may be abundant. The color of ball clay is nearly white, but some colors range from pink to brown through shades of gray to black. After firing, it is usually almost white. Ball clays require between 40 and 65 percent water of plasticity to become workable. Its plasticity, toughness, high green strength, and adhesion are the outstanding characteristics of ball clay. When fired, ball clay becomes dense and vitreous and its temperature of deformation (melting) is between 1,670° and 1,765 °C.

Ball clay was first mined in the United States in 1860 near Paris, Tenn., for use by the local pottery industry. Steady production of ball clay began in 1894 when Isadore Mandle shipped clay from western Tennessee to East Liverpool, Ohio (Whitlatch, 1940, p.2). Approximately 85 percent of the ball clay produced in the United States comes from the Gulf Coastal Plain (fig. 2). Tennessee is the largest producer, followed by Kentucky and Mississippi; Texas is a minor producer.

The best commercial-grade clay deposits are Eocene in age. Clay deposits occur in the Wilcox Group (upper Paleocene and lower Eocene) in Carroll, Henry, and Weakley Counties in Tennessee; Cherokee and Rusk Counties in Texas; in the Claiborne Formation (middle Eocene) of Graves County in Kentucky; and Benton and Panola Counties in Mississippi (table 1). The Wilcox and Claiborne Groups have a greater potential for commercial-grade ball clay than does the Jackson Group (upper Eocene).

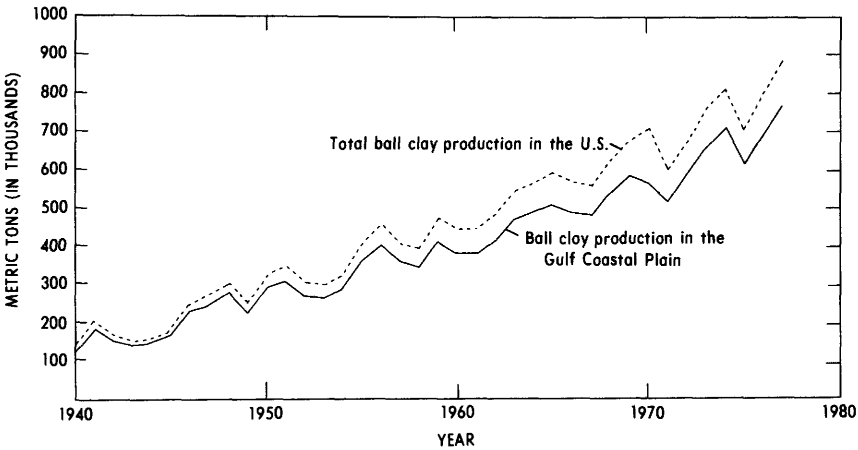

FIGURE 2.—Ball clay production from 1940 through 1977 (source: U.S. Bureau of Mines, 1940–1977).

The ball clay deposits occur as lenses interstratified with sand, silt, and lignite. The lenses range in thickness from less than 1 m to more than 5 m, and they are thinly laminated to thick bedded. The aggregate thickness of the clay in one mine may be as much as 10 m. Most of the clay is selectively mined to meet and maintain product specifications. The extent of minable clay deposits range from approximately 50 by 100 m to 300 by 800 m. Lignite and clayey lignite occur in discontinuous beds ranging in thickness from a few centimeters to more than 2 m and overlie or are interbedded with the ball clay.

Ten samples of ball clay from Kentucky, Tennessee, Mississippi, and Texas were analyzed for their mineral content. On the basis of these samples, there is no difference between clay from the Wilcox Group and clay from the Claiborne Group. The sand and silt content is less than 1 percent in all samples. Quartz is the major nonclay mineral, and feldspar is present in trace amounts in some samples. Both minerals are found in the clay fraction, which has a diameter of less than 4 μm. Because of its fine size, the amount of quartz is difficult to estimate, but it probably ranges between 5 and 15 percent. The predominant clay mineral is poorly crystalline kaolinite, which has an average ratio to other clay minerals of approximately 75 to 25. Smectite and (*Md*) illite each have an average ratio to other clay minerals of about 10:90; the range for smectite is from a trace to 20:80, and for illite, from a trace to 30:70.

The lack of knowledge about the details of geography, geomorphology, and soil development during Eocene time makes it difficult to provide a complete and thorough explanation about the origin of ball clays. The shapes and distribution of the clay bodies and the ecological information provided from a study of pollen assemblages (Olive and Finch, 1969, p.

TABLE 1.—*Mineralogical analyses of ball clay and kaolin deposits in Kentucky, Tennessee, Mississippi, and Texas*

[X, >5 percent of sample; tr, trace; L.O.I., loss on ignition]

Location	No. (pl. 1)	Color	Moisture (percent)	L.O.I. 1,000°C	Grain size (percent)			Clay minerals (ratio)				Nonclay minerals	
					Sand	Silt	Clay	Smectite	Illite	Mixed-layer	Kaolinite	Quartz	Feldspar
Jackson Group (upper Eocene)													
Kaolin:													
Dresser Minerals pit, 5.5 km south of Dolan, Jasper County, Tex.	28		16.2	6.2	tr	16	84	---	---	---	100	X	---
Claiborne Group (middle Eocene)													
Ball Clay:													
Clay pit, 35 km east of Hudsonville, sec. 32, T. 2 S; R.1 W., Benton County, Miss.	46	5YR8/1	1.3	7.7	3	4	93	tr	30	---	70	X	---
K-T Clay Co. pit, 4.25 km southeast of Grenshaw, sec. 16, T. 7 S., R.9 W., Panola County, Miss.	49	N8	2.6	7.0	2	3	95	20	tr	---	80	X	---
Old Hickory Clay Co. pit, 3.5 km west of Hickory, Graves County, Ky.	39	N9	1.3	10.0	tr	tr	100	tr	tr	---	100	X	tr
Kentucky-Tennessee Clay Co., pit, 8 km southeast of Mayfield, Graves County, Ky.	40	10YR8/1	1.8	10.8	tr	tr	100	5	15	5	75	X	tr

Wilcox Group (upper Paleocene and lower Eocene)													
Henderson Clay Products pit, 4.5 km north of Henderson, Rusk County, Tex.	33	5YR5/1	4.6	12.2	---	tr	100	15	5	tr	80	X	tr
Spinks Clay Co. pit, 1 km southwest of Come, Henry County, Tenn.	42	10YR6/1	1.7	14.0	tr	tr	100	20	10	tr	70	X	tr
United Sierra clay pit, 2.5 km west of Gleason, Weakley County, Tenn.	43	N9	1.3	8.4	tr	tr	100	10	20	tr	70	X	tr
Do	43	7.5YR4/1	4.1	32.2	tr	tr	100	20	5	5	70	X	tr
Spinks Clay Co., pit, 3 km south-southeast of Liberty, Weakley County, Tenn.	44	10YR7/1	2.5	13.2	1	tr	99	15	tr	---	85	X	tr
United Sierra clay pit, 7 km west of Huntingdon, Carroll County, Tenn.	45	10YR5/1	2.0	12.2	tr	tr	100	15	15	tr	70	X	---

15) suggest that the climate during Claiborne time was warm and humid, and seasonal rainfall was heavy. The terrain was a rather flat plain traversed by meandering, low-gradient, aggrading streams that occupied broad shallow valleys. The clay material was probably deposited in lagoons behind barrier beaches. In these quiet waters of the lagoon, the mud accumulated to form ball clays. Although the source of the clay material is not completely understood, some of it may have been derived from volcanic ash, and some was probably transported by water over a great distance.

BENTONITE DEPOSITS

Bentonite has a wide variety of physical properties that make it suitable for many different uses and applications. The principal use of bentonite is as a drilling mud, especially where freshwater is present in the rocks penetrated. The "sodium," "high swelling," or "Wyoming"-type bentonite has exchangeable sodium ions, and when wetted with water will increase 15–20 times in volume. The "calcium," "low-swelling," or "southern"-type bentonite has exchangeable calcium ions, and when wetted with water will increase 0–5 times in volume. According to Fisher (1965, p. 168), most calcium bentonites, when treated with a 0.25 percent solution of Na_2CO_3, increase their swelling capacity 700 to 1,000 percent. The swelling betonite has excellent dry properties and is used in bonding foundry sand and pelletizing iron ore. The nonswelling bentonite has good green-bond properties and is used in foundries where green-mold techniques are applied. Bentonite is also used in petroleum refining as a catalyst and as a fuller's earth in clarifying and processing mineral and vegetable oils. Some bentonite is treated or "activated" with acid to improve its effectiveness in processing oils. Bentonite is also used as a carrier for insecticides and fungicides, and minor quantities are used for sealing irrigation ditches, canals, and reservoirs.

Bentonite production in the United States has increased more or less steadily since the first shipment for commercial use in 1888 from Rock Creek, Wyo., by William Taylor (Knight, 1897). Production of bentonite in the Gulf Coastal Plain increased during the early 1950's, but has remained constant for the past 25 years. In 1977, the Gulf Coastal Plain produced about 11 percent of the total bentonite production (fig. 3). Texas is the biggest producer of bentonite in the Gulf Coastal Plain, followed by Mississippi and Alabama.

Commercial-grade bentonite deposits in the central and western Gulf Coastal Plain range in age from Late Cretaceous to Miocene. Deposits of

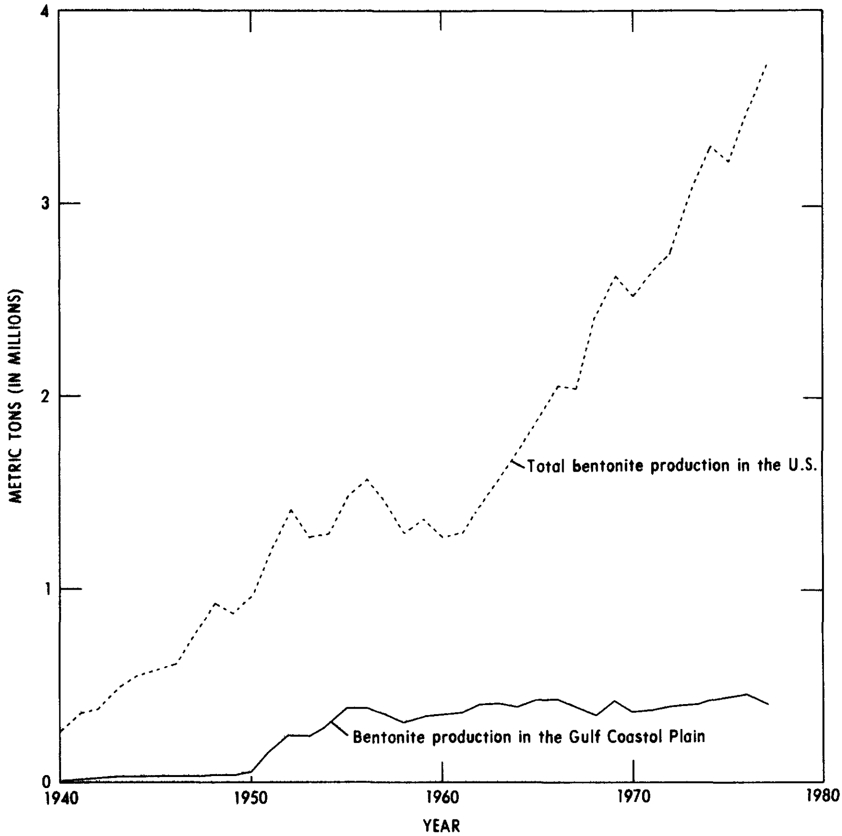

FIGURE 3.—Bentonite production from 1940 through 1977 (Source: U.S. Bureau of Mines, 1940–1977).

Late Cretaceous age occur in Mississippi (Eutaw Formation) and in Alabama (Ripley Formation). Bentonite deposits from the Midway Group (Paleocene) occur in Tennessee and Mississippi. Bentonites that are Eocene in age occur in the Claiborne and Jackson Groups of Texas. One active bentonite pit is in the Catahoula Formation (Miocene) of Texas, and two old abandoned bentonite pits are in the Fleming Formation (Miocene) of Louisiana. In general, commerical bentonite is found in the older units of the eastern part of the Gulf Coastal Plain and in the younger units in the western part.

The bentonite occurs as lense-shaped, massively bedded bodies with gravel, sand, silt, and limestone or marl. The bentonite beds range in thickness from about 1 m to 6 m. The minable deposits have an areal extent of approximately 135 by 225 m to 1,000 by 1,200 m, with less than 10 m of overburden. The color of dry bentonite ranges from medium gray (N5) to white (N9), but pale brown (7.5YR7/2), yellowish gray (10YR8/1) and brownish gray (2.5Y6/1) (Munsell Color Co., 1954) colors are also common.

Twenty-one samples of bentonite from active, inactive, and abandoned pits were analyzed for their mineral content (table 2). On the basis of these few samples, the deposits with the highest amount of smectite (90–100) are in the Upper Cretaceous units, the Claiborne Group (lower and middle Eocene), and the Jackson Group (upper Eocene). Bentonitic clay, which has a smectite to other clay minerals ratio of about 75:25, is also being mined from units of Paleocene age (Midway Group) and of Oligocene and Miocene ages (Catahoula and Fleming Formation). If we eliminate the bentonite deposits at No. 16 (table 2) because of its high sand content and the middle bed of the deposit at No. 10 (table 2) because of its high glass content, the sand and silt fractions for commercial bentonite average about 1 and 3 percent respectively, and the clay fraction averages about 96 percent. Quartz is the major nonclay mineral in most samples; plagioclase and heulandite are found in minor to trace amounts in some samples; and feldspar, biotite, and muscovite are found in trace amounts in a few samples (table 2).

The first discussion on the origin of Upper Cretaceous bentonites was presented by Condra (1908, p. 13). According to Condra, a thin bed that appeared to be bentonite was considered by Professor J. E. Todd to have been derived from volcanic ash. Later, Hewitt (1917) and Wherry (1917) established that bentonites were formed from the alteration of volcanic ash. Apparently during Late Cretaceous time where there was an arc of volcanic activity southeast of the Gulf of Mexico (Lyons, 1957, Ross and other, 1929) which may have been the source for the ash material. There is very little evidence on the location of the volcanoes that gave rise to the ash falls during Tertiary time. Possibly, those volcanoes that were active during Late Cretaceous time may have also became active again during Tertiary time. The volcanic ash was deposited in a marine environment of relatively quiet waters in lagoons and near-shore bays. Glass, the major component of volcanic ash, is soluble in alkaline solutions, and, conceivably, chemical alteration of the fine-grained ash could have begun while the ash settled in water. Much of the silica, the most abundant chemical element in volcanic ash, was removed by water circulation. Because of this, few or no chert beds are associated with the bentonite deposits in the Gulf Coastal area, although such beds would be present if the silica had been leached after deposition.

BENTONITE OCCURRENCES IN TEXAS

For reconnaissance purposes, 29 samples (table 3) of possible bentonite deposits were collected from roadcuts and streambanks throughout eastern Texas. The sample locations were picked because Dietrich and

Lonsdale (1958), Maxwell (1962), and Fisher (1965) indicated that these locations may be areas of potential bentonite deposits. The samples are from formations that range in age from Late Cretaceous to Miocene. Only 8 of 29 samples were found to contain enough clay and smectite equal to the bentonites sampled from active and abandoned pits (table 2), where samples averaged approximately 95 percent clay and ratio of smectite to other clay minerals was 85:15.

Three of the eight bentonite samples are from Upper Cretaceous formations (Ozan and Navarro Group), one sample is from the upper Eocene (Jackson Group), and four samples are from Miocene formations (Catahoula and Fleming). A comparison was made of the upper Cretaceous bentonites from three active pits (pl.1, Nos. 50(2) and 51 and table 2) in Alabama and Mississippi with the three reconnaissance samples also Cretaceous in age (pl. 1, Nos. 7, 8, and 35, and table 3). Although both groups of samples have similar grain-size compositions, the amount of smectite in the samples from Alabama and Mississippi is slightly higher. The reverse seems to be true for the Tertiary age bentonite on the basis of a comparison of six active pits (pl. 1, Nos. 25, 31, 12, 13, 15, and 16, and table 2) and five reconnaissance samples of Tertiary age from three areas (pl. 1, Nos. 26, 2, and 1, and table 3).

The best reconnaissance sample is No. 2 (pl. 1 and table 3) from Jim Hogg County, Tex. This sample contains a trace of sand, 5 percent silt, and 95 percent clay. Smectite is the only clay mineral. The nonclay minerals are quartz and a trace of feldspar and biotite. According to the geologic map, the sample is from the Catahoula Formation (Oligocene and Miocene) (Barnes, 1976). The sample was collected from a roadcut that exposed at least 4.5 m of bentonite. Another good reconnaissance sample is No. 1 (pl. 1 and table 3) from Zapata County, Tex. This grab sample from a roadcut is composed of 100 percent smectite and a trace of quartz sand and a trace of calcite. The sample is from the Jackson Group of late Eocene age.

CONCLUSIONS

The Mississippi Embayment part of the Coastal Plain will continue to be the major producing area of ball clay because no areas in the United States contain a comparable quality and quantity of clay. The best grade commercial clay comes from the Wilcox Group (upper Paleocene-middle Eocene) and the Claiborne Formation (middle Eocene). These two units are distinct from the other Tertiary and Upper Cretaceous units because they contain large amounts of kaolinite, some illite, and little or no smectite. Also, the highest quality clay contains no sand, no silt, and quartz is usually present in the clay-size fraction. Because of the lenticular nature of the clay bodies, close-spaced drilling, detailed sampling, mineralogic

TABLE 2.—*Mineralogical analyses of bentonite deposits in*

[X, >5 percent of sample; L.O.I., loss on ignition; G, glass; Q, quartz;

Location	No. (pl. 1)	Thickness (meters)	Color	Moisture (percent)	L.O.I. 1,000°C
Fleming and Catahoula Formations (Miocene and Oligocene)					
Milwhite Co., Inc. pit, 1.5 km west of Riverside, Walker County, Tex.	25	3.0-3.5	N8	17.1	8.5
		3.0-4.0	N8	22.6	12.1
		1.5	N7	18.3	11.4
Abandoned clay pit, 1.5 km southwest of Hornbeck, Vernon Parish, La.	31	2.5	10YR8/1	22.6	9.5
Abandoned clay pit, 7 km west-southwest of Begalusa, Washington Parish, La.	32		N7	20.3	8.9
Jackson Group (upper Eocene)					
Abandoned clay pit, 8.5 km southeast of Waelder, Gonzales County, Tex.	12		7.5YR6/1	20.7	14.1
Balcones Mineral Corp. pit, 2.5 km west of Flatonia, Fayette County, Tex.	13	3.0	7.5YR7/2	17.2	10.7
Milwhite Co., Inc. pit, 4 km northwest of Muldoon, Fayette County, Tex.	15	2.5	N5	26.7	14.4
Abandoned clay pit, 5 km north of Muldoon, Fayette County, Tex.	16		10YR8/1	17.9	8.5
Claiborne Group (middle and lower Eocene)					
Southern Clay Products Inc. pit, 7.5 km southeast of Gonzales, Gonzales County, Tex.	10	0.8	N9	11.5	17.2
		1.0	N9	8.3	9.6
		2.5	N9	14.8	17.1
Abandoned clay pit, 0.5 km west of Moffitt, Angelina County, Tex.	27		5Y9/1	31.2	15.9
Midway Group (Paleocene)					
Southern Clay Inc. pit, 5 km south of Paris, Henry County, Tenn.	41	6.0	N6	5.4	7.4
Oil Dry Corp pit, 6 km northeast of Ripley, Tippah County, Miss.	47		5Y5/1	36.5	13.8
		2.5-6.0	2.5Y6/1	34.6	11.1
Oil Dry Corp pit, 4 km west of Ripley, Tippah County, Miss.	48	6.0	10YR7/1	8.4	8.2
Ripley and Eutaw Formations (Upper Cretaceous)					
American Colloid Co. pit, 7 km south of Aberdeen, Monroe County, Miss.	50	0.3	N5	10.9	12.2
		0.9	5Y6/1	10.5	12.7
International Minerals Corp pit, 7 km south of Aberdeen, Monroe County, Miss.	50	1.0	N6	25.5	17.9
American Colloid Co. pit, 2.5 km northeast of Sandy Ridge, Lowndes County, Ala.	51	4.5-6.0	N7	27.5	16.6

Alabama, Mississippi, Louisiana, Tennessee, and Texas
F. feldspar; P. plagioclase; B. biotite; M. muscovite; H. heulandite]

Grain size (percent)			Clay minerals (ratio)				Nonclay minerals						
Sand	Silt	Clay	Smectite	Illite	Mixed-layer	Kaolinite	G	Q	F	P	B	M	H
Fleming and Catahoula Formations (Miocene and Oligocene)—Continued													
tr	tr	100	25	5	tr	70	---	X	---	---	---	---	---
tr	tr	100	90	5	tr	5	---	X	---	---	tr	---	---
tr	3	97	70	15	---	15	---	X	---	---	tr	---	---
tr	11	89	95	tr	---	5	---	X	---	tr	---	---	---
2	13	85	85	5	---	10	---	X	---	---	---	---	---
Jackson Group (upper Eocene)—Continued													
6	2	92	100	---	---	---	---	X	---	---	---	---	X
2	2	96	90	---	---	10	---	X	---	---	---	---	---
2	4	94	100	tr	---	tr	---	X	---	---	---	---	tr
39	8	54	95	5	---	tr	---	X	---	X	---	tr	tr
Claiborne Group (middle and lower Eocene)—Continued													
tr	tr	100	100	---	---	---	---	tr	---	---	---	---	---
4	52	44	50	---	---	50	X	tr	---	---	---	---	---
tr	tr	100	100	---	---	---	---	---	---	---	---	---	---
1	4	95	100	---	---	---	---	tr	---	tr	---	---	---
Midway Group (Paleocene)—Continued													
tr	1	99	50	25	tr	25	---	---	---	---	---	---	---
tr	tr	100	70	30	---	---	---	---	---	---	---	---	tr
tr	tr	100	80	20	---	tr	---	X	---	---	---	---	tr
tr	tr	·100	90	10	---	---	---	X	---	---	---	---	tr
Ripley and Eutaw Formations (Upper Cretaceous)—Continued													
2	1	97	100	---	---	---	---	---	tr	---	---	---	---
1	3	96	100	---	---	---	---	---	tr	---	tr	---	---
3	2	95	100	---	---	---	---	tr	tr	---	tr	---	---
tr	8	92	100	---	---	---	---	---	---	---	tr	---	---

TABLE 3.—*Mineralogical analyses of reconnaissance*

[X, >5 percent of sample; L.O.I., loss on ignition;Q, quartz; F, feldspar; M,

Location	No. (pl. 1)	Latitude	Longitude	Thickness (meters)	Color
Fleming and Catahoula Formations (Miocene and Oligocene)					
Streambank, 5 km west of Tulsita, Bee County.	4	28°38'49"N.	97°52'52"E.		N5
State 1097 roadcut, 3.3 km northeast of Montgomery, Montgomery County.	17	30°24'42"N.	95°40'30"E.		7.5YR5/4
State 350 roadcut, 11 km west of Moscow, Polk County.	26	30°53'50"N.	94°56'00"E.	1 1 1	5Y7/2 N4 5Y8/2
State 649 roadcut, 26.5 km south-southeast of Miranda City, Jim Hogg County.	2	27°12'37"N.	98°56'00"E.		N9
Gully near old road, 5 km west of Ebenezer, Jasper County.	29	30°01'55"N.	94°12'03"E.		N8
Jackson Group (upper Eocene)					
State 16 roadcut, 16.5 km northeast of Zapata, Zapata County.	1	26°59'29"N.	99°09'39"E.		5Y8/1
San Antonio River and road, 5.5 km southwest of Falls City, Karnes County.	5	28°56'57"N.	98°03'42"E.		2.5Y7/2
State 887 roadcut, 3.5 km southwest of Gillett, Karnes County.	6	29°06'39"N.	98°49'00"E.	1.5	N5
Roadcut 9 km south of Gonzales, Gonzales County.	9	29°25'12"N.	97°26'36"E.		N5
Peach Creek and road, 22.3 km northeast of Gonzales, Gonzales County.	11	29°36'15"N.	97°15'24"E.		N5
Roadcut, 6 km northeast of I-10 and State 95 junction, Fayette County.	14	29°45'00"N.	97°05'30"E.	3	5YR7/1
Claiborne Group (middle and lower Eocene)					
State 97 roadcut, 5 km northeast of Catulla, LaSalle County.	3	28°27'03"N.	99°11'06"E.	1.2	10YR8/1
State 489 roadcut, 6.5 km east of Lanely, Freestone County.	22	31°35'22"N.	95°59'21"E.		5YR6/4
Roadcut 4.5 km northeast of Middleton, Leon County.	23	31°12'00"N.	95°50'12"E.		10YR6/4
Roadcut 6.5 km southeast of Crockett, Houston County.	24	31°17'51"N.	95°23'54"E.		10YR7/1
State 103 and 147 junction roadcut, San Augustine County.	30	31°23'45"N.	94°11'25"E.		10YR7/3
Wilcox Group (lower Eocene and upper Paleocene)					
Roadcut 0.75 km north of Center, Limestone County.	19	31°31'00"N.	96°25'31"E.		2.5Y7/4
Roadcut 3.5 km south of New Hope, Robertson County.	20	31°22'39"N.	96°16'18"E.		10YR8/1
State 1124 roadcut, 1.3 km northwest of Young, Freestone County.	21	31°51'07"N.	96°05'15"E.		10YR7/1
Roadcut, 3 km west of I-30 and U.S. 259 junction, Morris County.	38	33°18'00"N.	94°45'48"E.		2.5Y7/2

samples of bentonite from eastern Texas
muscovite; B, biotite; C, calcite; D, dolomite; G, gypsum]

Moisture (percent)	L.O.I. 1,000°C	Grain size (percent)			Clay minerals (ratio)				Nonclay minerals						
		Sand	Silt	Clay	Smectite	Illite	Mixed-layer	Kaolinite	Q	F	M	B	C	D	G
Fleming and Catahoula Formations (Miocene and Oligocene)—Continued															
15.3	7.2	45	20	35	75	20	---	5	X	tr	---	---	tr	---	---
18.2	8.7	24	25	51	80	---	---	20	X	---	---	---	---	---	---
14.5	26.7	1	3	96	95	---	---	5	X	---	---	---	tr	---	---
27.0	13.4	8	tr	92	95	tr	---	5	X	---	---	---	---	---	---
17.9	25.4	tr	tr	100	90	5	---	5	X	---	---	---	tr	---	---
30.3	10.1	tr	5	95	100	---	---	---	tr	tr	---	tr	---	---	---
22.4	8.3	tr	10	90	65	---	---	35	X	tr	---	---	---	---	---
Jackson Group (upper Eocene)—Continued															
10.4	16.2	tr	---	100	100	---	---	---	X	---	---	---	X	---	---
17.7	17.6	8	2	90	80	10	---	10	X	---	---	---	X	---	---
24.0	11.3	25	tr	75	100	---	---	tr	X	tr	---	---	tr	---	---
9.3	7.7	20	30	50	85	---	---	15	X	tr	---	---	---	---	---
5.0	9.4	30	10	60	95	---	---	5	X	tr	---	---	---	---	---
32.0	12.3	2	20	78	55	tr	---	45	X	---	---	---	---	---	---
Claiborne Group (middle and lower Eocene)—Continued															
6.0	20.2	7	3	90	80	5	---	15	X	---	---	---	---	---	X
24.7	10.6	5	30	65	50	20	---	30	X	tr	---	---	---	---	---
20.1	9.8	15	30	55	65	---	---	35	X	---	---	---	---	---	---
9.5	4.7	35	20	45	70	5	---	25	X	tr	---	---	---	---	---
14.2	5.7	40	25	35	40	---	---	60	X	---	---	---	---	---	---
Wilcox Group (lower Eocene and upper Paleocene)—Continued															
18.6	9.2	12	30	58	30	15	---	55	X	tr	---	---	---	---	---
21.1	7.3	4	40	56	65	15	---	20	X	tr	tr	---	---	---	---
13.7	5.0	30	30	40	70	10	---	20	X	tr	---	---	---	---	---
17.8	8.1	10	40	50	60	10	---	30	X	tr	---	---	---	---	---

TABLE 3.—*Mineralogical analyses of reconnaissance*

Location	No. (pl. 1)	Latitude	Longitude	Thickness (meters)	Color
Midway Group (Paleocene)					
Roadcut, 2.3 km south of Dike, Hopkins County.	37	33°13'07"N.	95°28'50"E.		N5
Upper Cretaceous					
Claypit for cement, 3.5 km west of State 123 and 1101 junction, Guadalupe County.	7	29°43'51"N.	97°59'06"E.	6	2.5Y6/2
Roadcut at junction of State 123 and 1101, Guadalupe County.	8	29°44'06"N.	97°56'42"E.		N4
Roadcut, 2 km northwest of Mastang, Limestone County.	18	31°41'42"N.	96°45'15"E.		N5
Roadcut, 4.5 km north of Cooper, Delta County.	34	33°24'45"N.	95°41'12"E.		N4
Roadcut, 0.8 km east of Biardstown, Lamar County.	35	33°32'20"N.	95°30'00"E.	4.5	2.5Y6/2
U.S. 82, roadcut, 3.5 km east of Annona, Red River County.	36	33°34'51"N.	94°52'45"E.	2	7.5YR7/2

analyses, and ceramic testing are needed before adequate future reserves of ball clay can be proved.

The demand for bentonite from the Gulf Coastal Plain will probably not increase much over its present level even though U.S. bentonite production has tripled during the past 20 years. The calcium-type bentonite from Texas, Louisiana, Mississippi, and Alabama does not have the same properties as the sodium-type bentonite from Wyoming. Bentonites from the Claiborne Group (middle Eocene) and Fleming Formation (Miocene) have the best swelling properties and are the most suitable of the Gulf Coastal Plain clays for use in drilling muds. The fact that resources of calcium bentonite are extensive (Wayland, 1970, p. 27) indicates an adequate supply for a long time at the current rate of production.

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samples of bentonite from eastern Texas—Continued

Moisture (percent)	L.O.I. 1,000°C	Grain size (percent)			Clay minerals (ratio)				Nonclay minerals						
		Sand	Silt	Clay	Smectite	Illite	Mixed-layer	Kaolinite	Q	F	M	B	C	D	G
Midway Group (Paleocene)—Continued															
11.6	4.1	20	35	45	75	tr	---	25	X	tr	---	---	---	---	---
Upper Cretaceous—Continued															
18.3	14.2	tr	5	95	85	5	---	10	X	tr	---	---	X	tr	---
27.8	13.5	5	5	90	95	tr	---	5	X	---	---	---	tr	---	---
23.8	9.4	8	10	82	100	---	---	---	X	tr	---	---	tr	---	---
27.7	5.6	3	42	55	95	---	---	5	X	---	---	---	tr	---	---
20.8	7.4	tr	---	100	90	---	---	10	X	tr	---	---	---	---	---
21.3	9.2	9	25	66	95	tr	---	5	X	tr	---	---	---	---	---

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