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CLAYS

By Robert L. Virta

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The amount of clay sold or used by domestic producers increased slightly in tonnage to 43 million metric tons and 7% in value to $1.6 billion. Production of bentonite, fuller's earth, and kaolin increased in 1990. Ball clay, common clay and shale, and fire clay production decreased. Common clays accounted for 61% of the tonnage, and kaolin accounted for 66% of the value of clays produced in 1990. Imports increased 7% in tonnage to 29,550 tons and 10% in value to 12.0 million. Exports increased 10% in tonnage to 4.1 million tons and 6% in value to $584.4 million. Clays were produced in 44 States and Puerto Rico. The seven leading producer States, in descending order, were Georgia, Wyoming, Ohio, California, Texas, Alabama, and North Carolina.

DOMESTIC DATA COVERAGE

Domestic production data for clays are developed by the U.S. Bureau of Mines from one voluntary survey of U.S. operations. Of the 1,080 operations covered by the survey, 944 responded, representing 88% of the total clay and shale production sold or used shown in table 1.

TABLE 1-3 to be inserted here.

BACKGROUND

Definitions, Grades, and Specifications

Clays are categorized into six groups by the U.S. Bureau of Mines. The categories are kaolin, ball clay, fire clay, bentonite, fuller's earth, and common clay and shale. The definitions listed in this work for the high-alumina clays, kaolin, ball clay, and fire clay are similar to those in U.S. Bureau of Mines Information Circular 8335.[1]

Kaolin, or china clay, is defined as a white, claylike material composed mainly of kaolinite and other kaolin-group minerals, such as halloysite and dickite. Kaolin has a specific gravity of 2.6 and a fusion point of 1,785° C. Kaolin is classified according to the method of preparation (crude, air-separated, water-washed, delaminated, air-dried, calcined, slip, pulp, slurry, or water suspension) and on specific physical and chemical properties.

Ball clay is a plastic, white-firing clay used mainly for bonding in ceramicware. The clays are of sedimentary origin and consist mainly of the kaolinite, sericite mica, and organic matter. Ball clays usually are much finer grained than kaolins and are renowned for their plasticity. They are classified according to the method of preparation (crude, shredded, air-floated, water-washed, or slurry) and specific physical and chemical properties.

Fire clay is defined as detrital material, either plastic or rocklike, that commonly occurs as underclay below coal seams. Low concentrations of iron oxide, lime, magnesia, and alkalies in fire clay enable the material to withstand temperatures of 1,500° C or higher. It is composed mainly of kaolinite. Fire clays also contain other clays such as diaspore, burley, burley-flint, ball clay, and bauxitic clay and shale. Fire clays generally are used for refractories or to raise vitrification temperatures in heavy clay products. The fired colors of fire clays range from buffs to grays. Fire clays are

classified according to their physical and chemical properties and the characteristics of the products made from them.

Bentonite is a clay composed primarily of smectite minerals. The primary smectite mineral is usually montmorillonite. Swelling-type bentonite has a high-sodium ion concentration. Its volume increases 15 to 20 times its dry volume when wetted with water. Nonswelling bentonites usually are high in calcium. Bentonite is classified according to its physical and chemical properties, with particular emphasis on particle size and swelling index.

The term "fuller's earth" is derived from the first major use of the material, which was for cleaning textiles by fullers. Fuller's earth does not refer to a clay with a specific composition or mineralogy. It is defined as a nonplastic clay or claylike material, usually high in magnesia, that is suitable for decolorizing and purifying mineral and vegetable oils. They are composed mainly of the needle- and/or lath-shaped clay mineral attapulgite or varieties of montmorillonite. Fuller's earths containing opal or other forms of colloidal silica also are produced. Fuller's earths are classified according to their physical and chemical properties. Sepiolite-type clays are grouped with fuller's earths under the Bureau classification system.

Common clay is defined as a clay or claylike material that is plastic enough to mold easily. Its vitrification point is usually below 1,100° C. Shale is a laminated sedimentary rock that is formed by the consolidation of clay, mud, or silt. The common clays and shales are composed mainly of illite or chlorite. They also may contain kaolin and montmorillonite. Common clays and shales usually contain more alkali, alkaline earth, and ferruginous minerals and less aluminum than high-quality kaolins, fire clays, and ball clays. Iron present in the clay usually imparts a reddish color to the final product after firing. There is no formal classification of common clays and shales, although a clay may sometimes be referred to as common, brick, sewer pipe, or tile clay. Clay and shale are used in the manufacture of structural clay products such as brick, drain tile, portland cement clinker, and expanded lightweight aggregates.

The American Society for Testing and Materials, American Foundrymen's Association, American Oil Chemist's Society, American Petroleum Institute, Technical Association of the Pulp and Paper Industry, and other national organizations have developed tests and set standards for some applications. Many producers and consumers, however, use nonstandardized tests that are applicable to their specific needs. Individual companies often set the acceptable limits of mineralogical composition, particle size, and other physical and chemical properties. Detailed data on specifications have been published by the U.S. Bureau of Mines.[2]

Products for Trade and Industry

Because of the many types of clay and different qualities within each type, the consumption pattern and the products for trade and industry are constantly changing. Consumption of kaolin in refractories has been growing since 1970 because of the increasing popularity of castable, ramming, gunning, and plastic mixes that use calcined kaolin aggregates (grog) in their formulations.[3] The consumption of calcined kaolin grogs also has increased in refractory brick manufacturing, replacing imported calcined refractory-grade bauxite grogs. Consumption of bentonite has decreased for iron ore pelletizing and for more expensive drilling mud and foundry uses. Bentonite products for waterproofing and sealing in construction and reservoir uses also have gained in popularity. Attapulgite-type fuller's earth production, like bentonite, is finding increasing applications in the premium drilling mud industry.

Industry Structure

An estimated 350 companies operating more than 1,000 clays pits or mines reported production

in 1990; of these, 50 companies, most with multiple operations, accounted for approximately 50% of the tonnage and 80% of the value for all types of clay produced and sold or used. Clay production was reported in all States and Puerto Rico except Alaska, Delaware, Hawaii, Rhode Island, Vermont, Wisconsin, and the District of Columbia.

The leading clay-producing States were Georgia, 9.9 million tons; Ohio, 2.5 million tons; Wyoming, 2.5 million tons; Texas, 2.3 million tons; Alabama, 2.3 million tons; North Carolina, 2.2 million tons; and California, 2.2 million tons. Most of the clay is mined by open pit methods. Less than 2% of U.S. clay output is from underground mines in 1990. Most of the underground production is in Pennsylvania, Ohio, and West Virginia, where the clays are mainly underclays associated with coal and suitable for refractory uses.

Forty-three firms operated 130 kaolin mines in 13 States. In 1990, three large, diversified firms accounted for about 60% of total domestic kaolin output. Most large kaolin producers have operations in Georgia, which accounted for 78% of the kaolin production.

The ball clay industry is small, with 6 producers operating 27 mines in 5 States in 1990. Three of the producers were large, diversified firms with widespread foreign and domestic mineral interests. Tennessee ball clay production represented about 69% of the total output.

Fireclay producers were mostly refractories manufacturers that used the clays in firebrick and other refractories. Seventy-two mines were operated in 1990 by 26 firms in 6 States.

Firms producing bentonite operated 132 mines in 13 States. Four producers were large diversified firms with international mineral operations; three of the firms had interests in other types of clay in the United States. Wyoming was the leading State, accounting for 73% of the total output. Swelling-type bentonite is produced mainly in Wyoming and Montana and nonswelling-type bentonite is produced in Mississippi and Texas. The United States is the world's largest producer and exporter of bentonitic clays.

Fourteen companies produced fuller's earth from 29 mines in 10 States. Fourteen of the mines were in the attapulgite-fuller's earth areas of Florida and Georgia. These two States accounted for 43% of domestic production. Most producers were small independent firms, but three were large diversified corporations with international mineral interests. The world's fuller's earth needs are supplied from relatively few areas. The United States is the world's largest producer and user of fuller's earth.

Firms producing common clay and shale in 1990 were manufacturers of structural clay products, clay pipe, lightweight aggregates, and cement. Most companies mined the clays used in making their products. Private mining contractors and haulers were employed in many of the operations. Some producers were diversified firms having interests in metals and other nonclay products. Some companies owned and operated several clay pits and plants in order to cover a large market area. The economic radius for shipment of common clay or shale products is usually 200 miles or less. The high cost of transport promotes the development of local ownership companies, or in the case of a large firm, the ownership and operation of several strategically located pits and associated fabricating plants.

Geology-Resources

Clay is formed by the mechanical and chemical breakdown (weathering) of rocks. The weathering products consist of mineral grains and rock fragments of different size and different physical and chemical properties. The nonplastic portion consists of altered and unaltered rock fragments (grit), which are usually quartz, micas, feldspar, and iron oxides. The plastic portion usually is composed of clays and is low in grit.

Clays may be classified as residual or sedimentary. Residual clays are deposited in the same lo-

cation in which they were formed. Sedimentary clays are those that have been transported, usually by water, and deposited elsewhere.[4] Sedimentary clays often undergo further alteration and classification during transport. Kaolin deposits in Georgia and South Carolina are sedimentary. Kaolin deposits in North Carolina and English china or kaolin clay deposits are residual.[5] The Kentucky and Tennessee ball clays and the Missouri fire clays are sedimentary deposits. Most bentonites, montmorillonites, and fuller's earth were formed in place through the weathering of volcanic ash or tuff. The attapulgite-type fuller's earth deposits of Florida and Georgia were probably not formed from volcanic ash or tuff. Geologists have never found any evidence of volcanic materials associated with these deposits.[6]

The definitions of reserves and reserve base are published in U.S.Geological Survey Circular 831, "Principles of a Resource/Reserve Classification for Minerals." Reserves are the part of an ore body that can be economically extracted at the time of evaluation. Reserve base is the part of an ore body that meets specified minimum physical and chemical criteria related to current mining and production practices. Reserve base includes reserves, marginal reserves, and subeconomic resources.

Common clays and shale deposits are found throughout the United States. Clays and shale were mined commercially in 44 States and Puerto Rico. Domestic resources are almost unlimited. Not all deposits, however, are near potential markets, and most deposits are not suitable for all applications. For example, most common clay or shale deposits can be used to manufacture common brick, but the color or strength of the final product may not meet the requirements of the local market. Relatively few deposits are suitable for manufacture of lightweight aggregate. Even with these limitations of location and use, resources of common clay and shale are "virtually unlimited."

U.S. reserves of other types of clays that are owned or controlled by domestic producers are estimated to be about 700 million tons. U.S. reserves of kaolin are estimated to be 400 million tons; ball clay, 30 million tons; fire clay, 100 million tons; bentonite, 120 million tons; and fuller's earth, 60 million tons.

Large quantities of high-quality kaolin suitable for paper-coating and paper-filler are found in Georgia. A small area in Georgia and Florida contains sizable reserves of attapulgite-type fuller's earth. Most bentonite for iron ore pelletizing and oil-well-drilling muds is mined in Wyoming. Fire clay deposits, such as those found in Missouri, are widespread. Deposits of high-quality fire clay are nearing depletion. Kentucky and Tennessee are two of only a few States that have sizable deposits of ball clay.

Technology

Exploration.—Exploration begins with an understanding of the geological occurrence of the clays of interest. With this knowledge, potential economic deposits can be located. Auger or core drills are then made to deliniate the size and shape of the deposit and to obtain material for testing.

Kaolins usually are evaluated for filler and ceramic applications. The grit, particle size, brightness, and leachability are determined. Air-floated clays normally require only grit and brightness determinations. Kaolin, ball clay, and fire clay for ceramic and/or refractory applications are analyzed for grit, brightness, green and dry strengths, fired color, and iron and alumina contents. The common clays and shales usually are tested according to the intended end use, such as brick, structural-drain tile, or lightweight aggregate. Usually, prepared specimens are tested for plasticity, green strength, shrinkage, vitrification temperature range, etc. For lightweight aggregates, the bloating range is determined. Bentonites and fuller's earth clays are difficult to evaluate because there is no standard testing procedures or specifications. Generally, they are processed to meet the purchaser's specifications.

Mining. – Most clays are mined from open pits using modern surface mining equipment such as draglines, power shovels, front-end loaders, backhoes, scraper-loaders, and shale planers. Some kaolin is extracted by hydraulic mining and dredging. A few clay pits are operated using crude hand-mining methods. A small number of clay mines, principally in underclays in coal mining areas, are mined underground using room-and-pillar methods. Clays usually are transported by truck from the pit or blending areas to the processing plants. Rail, conveyor belt, and in the case of kaolin, pipelines also are used.

About 100% of the clay is recovered from the minable beds in most open pit operations. Approximately 75% is recovered in underground operations. The waste-to-clay ratio is highest for kaolin, about 7:1, and lowest for common clay and shale, about 0.25:1.

Processing. – Clays are used in a large number of products so they must be treated in many different ways. Processing can consist of very simple and inexpensive crushing and screening for some common clays. It also can consist of very elaborate and expensive grinding, sizing, bleaching, delamination, etc. for paper-coating clays and high-quality filler clays for use in rubber, paint, plastic, and other products. In general, processing does not appreciably alter the chemical or mineralogical characteristics of the clays. The two exceptions are calcining and cation exchange.

Significant processing losses occur with kaolin and fuller's earth. About 40% of the kaolin and 30% of the fuller's earth delivered to the processing plants is discarded. Waste material from processing consists mostly of off-grade clays and small quantities of quartz, mica, feldspar, and iron-bearing minerals.

Kaolin. – Processing involves one or more of the following: crushing, blunging with dispersant, rough sedimentation, water fractionation, magnetic separation, ultraflotation, acid treatment, calcination, air floating, and attrition grinding, slurrying, and delaminating. Kaolins used for paper coating applications may be bleached and further delaminated by grinding, deflocculation, and elutriation to special sizes. Ultraflotation or wet magnetic separation treatment may be used to remove iron- or titanium-bearing minerals to obtain a whiter product.

Ball Clay. – Processing involves drying, shredding, pulverizing, air floating, and slurrying.

Fire Clay. – Processing involves crushing, calcining, and blending.

Bentonite. – Processing involves weathering, drying, grinding, sizing, granulation, and the use of additives for cation exchange.

Fuller's Earth. – Processing involves blunging, extruding, drying, crushing, grinding, sizing, and dispersing.

Common Clay and Shale. – Processing involves crushing, blunging, extruding, and drying. Common bricks, tile, lightweight aggregate, etc., require firing in a kiln. The kiln firing or drying operation produces a finished manufactured product.

Processing costs for clays range from a few cents per ton for some common clays to more than $400 per ton for some special paper-coating clays and high-quality clays that require very elaborate and expensive treatments.

Price schedules, although not complete, are available and are published regularly in trade journals such as the American Paint and Coatings Journal, Chemical Marketing Reporter, and Industrial Minerals (London).

Federal tax laws allow clay producers a depletion allowance on both domestic and foreign gross income not to exceed 50% of net income with depletion deduction. Depletion allowances are as follows: ball clay, bentonite, kaolin or china clay, sagger clay, and clay used or sold for purposes dependent on its refractory properties, 14% domestic and 14% foreign; fuller's earth, 14% domestic and 14% foreign; clay used for extraction of alumina or aluminum compounds, 22% domestic; clay used or sold for use in manufacturing drainage and roofing tile, flower pots, and kindred products,

5% domestic and 5% foreign; clay and shale used for making brick, tile, and lightweight aggregate, 7.5% domestic and 7.5% foreign. Severance taxes are levied by some producing States.

Byproducts and Coproducts

Firms in California, Florida, and Texas produce silica glass sand as a coproduct of its kaolin production. Flake mica is a byproduct in one kaolin operation in North Carolina. Bauxite is a coproduct in kaolin operations in Alabama and Georgia. Clay and limestone for cement manufacture are often produced from the same property and reported as coproducts or byproducts even though they are usually mined separately from different formations or beds. Sand, gravel, and stone aggregates are occasionally produced together with common clays.

Economic Factors

Economic factors affecting clays vary in importance with type, quality, and intended end use. The cost of transportation is an important factor for the common clay and fire clay industries; mines must be close to consumers to be cost competitive. Other types of clays are less abundant and have higher unit values. They can be shipped greater distances from the mines and still be cost competitive. For example, paper-coating clay from Georgia and attapulgite-type fuller's earth from Florida and Georgia can be shipped nationwide. Bentonite for iron ore pelletizing from Montana and Wyoming can be shipped a considerable distance to the iron ore centers. In some of these cases, the shipping costs exceed the value of the clays at the mine or processing plant.

Because most clays are relatively low-cost materials in the crude state, mining costs must be kept as low as possible. Cost of the crude clays ranges from less than $3 per ton for some common clays to above $20 per ton for some of the higher quality materials.

Very little clay is imported because transportation costs would make the clays noncompetitive in price. Consequently, import duties have little impact on the amount of clays imported.

Operating Factors

To manufacture finished clay products, producers require equipment to mine and process the crude clay and a kiln for firing or drying their products. Mining, processing, and manufacturing are all energy-intensive operations. Many clay producers converted to coal from oil firing and gas firing. However, the conversion to coal and/or wood as a kiln fuel is gaining in popularity where feasible in heavy clay and refractory products manufacturing and in bentonite processing.

Losses in mining are extremely small, except in underground mining where recovery will average about 75%. Processing losses for material receiving, crushing, grinding, mixing, shredding, blending, and drying also are insignificant. Losses from washing, sizing, etc., reach 30% or 40%.

Clay mining lacks many of the hazards associated with other types of mining because only a few deposits require the use of explosives and most mines are open pit earth-moving operations. Domestic mine employment in 1990 was estimated to be 2,000 workers. Domestic mill employment was estimated to be 9,100 workers.

ANNUAL REVIEW

Issues

Clay mining has an environmental impact because of the disturbance to the land. Overburden is moved and clays are removed, leaving a depression or pit. State laws usually require leveling or recontouring of the disturbed area and planting trees or grasses to prevent or minimize erosion. For processing, the impoundment of slimes and dust control are usually required. The rules for dis-

Common Clay and Shale.—Domestic sales or use of common clay and shale decreased 2% in tonnage to 26.1 million tons and increased 8% in value to $152 million. Of the nine major producing States, production increased in Alabama, Indiana, and Missouri, and decreased in California, Georgia, Michigan, North Carolina, Ohio, and Texas. Common clay and shale represented about 61% of the quantity but only 9% of the value of total domestic clay production.

TABLE 20 to be inserted here.

Domestic clay and shale are generally mined and used captively to fabricate or manufacture products. Less than 10% of the total output is usually sold. The average unit value for all common clay and shale produced in the United States and Puerto Rico increased 11% to $5.82 ton. The reported unit value ranged from $5 per ton to $36 per ton.

The Department of Commerce reviewed ceramic tile imports from Mexico for January 1, 1987, to December 31, 1987. It concluded that duties will be zero for 47 companies and 1.29% ad valorem for all other firms. The Agency also reviewed brick imports for January 1, 1986, to August 23, 1986. It concluded that duties will be zero for 22 firms and 4.44% ad valorem for all other firms. The decision is based on benefits received by these companies under Government financial aid programs.[20]

S.V. Farming Corp. submitted a proposal to expand its clay operation to approximately twice its current size of 59 acres. S.V. Farming produces clay for lining and capping landfills.[21]

Western Aggregates Inc. announced a $14 million reconstruction of its lightweight aggregate plant in Colorado. Plant capacity will be 500,000 cubic yards of aggregate for construction applications.[22]

Carolina Solite Corp. was the center of controversy as residents protested its burning of chemical wastes as fuel. The company produces lightweight aggregate for cement and concrete applications. Caroline Solite uses approximately 6 million gallons of waste per year.[23]

Consumption and Uses

The manufacture of heavy clay products, including (1) building brick; sewer pipe; and drain, roofing, structural, terra cotta, and other tile; (2) portland cement clinker; and (3) lightweight aggregate, accounted for 47%, 17%, and 10%, respectively, of total domestic consumption.

TABLE 21 to be inserted here.

Kaolin has many industrial applications, and many grades are specifically designed for use as a filler in paper, paint, rubber, plastics,[24] and ceramics.[25] New uses are constantly being developed. Kaolin is a unique industrial mineral because it is chemically inert over a relatively wide pH range, is white in color, and has good covering or hiding power when used as a pigment or extender in coated films and filling applications. It also is soft and nonabrasive, has low conductivity of heat and electricity, and costs less than most materials with which it competes. Fillers and extenders must meet very rigid specifications such as particle size, color, brightness, and viscosity.[26]

Ball clays are extremely refractory and their use, largely in whitewares, imparts a high green strength as well as plasticity to the bodies. Although white-firing ball clays are preferable, fired products that range to cream or buff colors do not generally impair the quality of the whiteware products.

Fire clays are used mostly in commercial refractory products such as firebrick and block of many shapes, insulating brick, saggers, refractory mortars and mixes, ramming and gunning mixes, grog and crude aggregates, and many other products. Fire clays are also added to common clays to increase the vitrification range of sewer pipes and bricks.

The swelling sodium bentonites are used largely in drilling muds, in foundry sands, and in pelletizing taconite iron ores. The nonswelling or calcium bentonites are used mostly in conjunction with the swelling bentonites in foundry sand mixes in which the sodium bentonites provide dry strength and the calcium bentonites provide high green strength. Fuller's earth and calcium bentonites find application in decolorizing and purifying mineral, vegetable, and animal oils. Clays used to process animal or vegetable oils usually are activated by acid treatment. Acid treatment produces a highly absorbent sievelike structure. Attapulgite is used in drilling muds instead of sodium bentonites for drilling saltwater formations. Sodium bentonite "breaks the emulsion" or flocculates in brine, thereby destroying the gellike colloidal suspension required for drilling. The major uses for attapulgite and montmorillonite types of the fuller's earths are in pet waste and oil and grease absorbents because of their absorbent properties.

Bentonite also is used for foundry casting by the steel, iron, and nonferrous casting. The bentonite provides good green strength and desirable dry strength characteristics. Sodium bentonites are used in steel casting. Ion-exchanged bentonites are used for iron and nonferrous casting. There is increased use of mixtures of ion exchanged and sodium bentonites to meet the more stringent demands of the casting industry.[27]

Construction. – Common clays and shales are used to manufacture a wide variety of construction materials such as structural clay products, cement, and expanded aggregates.

Structural Clay Products. – Structural clay products such as building brick, drain tile, and vitrified sewer pipe are used in building construction, for sewer systems, to drain farmers' fields, and for many other uses. Other clays, such as kaolin, fire clay, or ball clay, could in many cases be used to produce equally suitable "heavy clay" products, but they are generally more refractory and valuable for other uses. Of the total clay produced, about one-third is consumed in the manufacture of these structural products.

Hydraulic Cement. – The portland cement industry requires alumina and silica as constituents in the manufacture of portland cement. Common clays provide a low-cost source of these materials.

Expanded Clay and Shale. – For this purpose, certain bloating qualities and strength are required. Lightweight concrete blocks, floors, walls, and other shapes made from expanded clay and shale have a lower overall weight, which results in savings in the design of the supporting framework. Also, products made from expanded clay and shale have better insulating qualities than equivalent products made with sand and gravel and crushed stone aggregates.

Refractories. – Refractories require strength at high temperatures, resistance to corrosion, low coefficient of expansion, and many other physical and chemical properties, depending on application. Clays with physical properties most suitable for general refractory use have been classed as fire clays. The current trend is for refractories designed for a specific use and castable mixes containing refractory aggregates and calcium aluminate cements.[28]

Paper Products. – Demand for clays for use as filler and coater in paper has followed the rapid increase in demand for paper. Kaolin is the principal clay used.

Other Uses. – Pottery and related products require good ceramic qualities, including plastic formation, desirable firing temperatures, color, etc. The principal clays meeting these and other specifications are ball clay and kaolin. Kaolin also is used as a raw material feed in formulating bottle and plate glass batches. Drilling mud is a scientifically designed mixture of several items. It contains, in addition to bentonite or attapulgite, ground barite for its high specific gravity.[29] Demand for bentonite in iron and steel production is based on its ability to form strong iron ore pellets from fine-grained taconite concentrates. Easily handled hard pellets are essential for efficient blast furnace operation.

Heavy Clay Products. – The value reported for shipments by the Bureau of the Census for heavy

clay products remained the same at $1.8 billion. The million standard brick count for building or common face brick increased slightly. Shipments of clay floor and wall tile decreased 6% while vitrified clay and sewer pipe fittings decreased 5%.

TABLES 22 and 23 to be inserted here.

Lightweight Aggregates.—Consumption of clay and shale in the production of lightweight aggregate increased 12% to 3.8 million tons. Concrete block, the largest category, (66% of total production), increased 22% while the second biggest consuming area, structural concrete (22% of total production), increased only slightly. The third largest segment, highway surfacing (7% of production), declined significantly. The other category, the smallest segment consisting essentially of market areas such as recreational and horticultural uses, increased 5%.

TABLE 24 to be inserted here.

Refractories.—All types of clay, except for fuller's earth, were used in manufacturing refractories. Kaolin, bentonite, and fire clay accounted for 32%, 31%, and 19%, respectively, of total clay used for this purpose. The remainder, ball clay and common clay and shale, was used chiefly as bonding agents. Bentonite, both swelling and nonswelling, was used as a bonding agent in proprietary foundry formulations imparting both hot- and green-strength to the sand.

The tonnage of clays used for refractories increased 6% and constituted 8% of total clay produced. The continued use of high-alumina clay-base refractories, mostly calcined kaolin grogs in monoliths, and the upturn in demand for the more conventional refractory bricks and shapes were largely responsible. The major refractory consuming industries—cement, foundry, glass, and ferrous and nonferrous metals—continued to undergo major changes in technology and production levels for their products.

TABLE 25 to be inserted here.

Filler.—Bentonite, fuller's earth, and kaolin are the principal filler clays. Kaolin, either air-floated, water-washed, low-temperature calcined, and/or delaminated, was used in the manufacture of adhesives, paint, paper, plastics, and rubber. Fuller's earth was used primarily in pesticides and fertilizers. Clays were used in pesticides and fertilizers as either thickeners, carriers, diluents, or prilling agents. Bentonites were used mainly in animal feeds.

Of the total clay produced, 13% was used in filler applications; of this, kaolin accounted for 87%; fuller's earth, 6%; bentonite, 3%; and ball clay, common clay and shale, and fire clay, 4%. Kaolin consumed as fillers increased 3% to 5.1 million tons. Use of paper-coating-grade kaolin increased 7%, and the use of paper-filler-grade kaolin decreased 6%. These two categories accounted for 84% of the total filler and extender category.

Absorbent Uses.—Absorbent uses for clays accounted for about 2.1 million tons or 5% of total clay consumption. Demand for absorbents increased 10%. Fuller's earth was the principal clay used for absorbent purposes. This application accounted for 83% of its entire output. Demand for clays in pet waste absorbents increased. The use of fuller's earth in floor or oil and grease absorbents, chiefly to absorb hazardous oily substances, accounted for 17% of the absorbent demand.

Drilling Mud.—Demand for clays in rotary-drilling muds decreased to about 747,000 tons and accounted for 2% of total clay production. Oil- and gas-well-drilling activity increased at the end of the year because of firmer oil prices brought about by Middle Eastern difficulties. Swelling-type bentonite remained the principal clay used in drilling mud mixes, although fuller's earth, used mostly in saltwater drilling techniques, and nonswelling sodium-activated bentonites were also used to a limited extent. Bentonite and fuller's earth accounted for 100% of the total amount of

Table 8.--Georgia kaolin sold or used by producers, by use
(Metric tons)

Use	1989				1990			
	Air-float	Unprocessed1/	Water-washed2/	Total3/	Air-float	Unprocessed1/	Water-washed2/	Total3/
Domestic:								
Adhesives	9,220	--	17,139	26,359	20,738	--	20,997	41,735
Aluminum sulfate and other chemicals	6,560	167,104	--	173,664	--	W	--	W
Asphalt tile and linoleum	3,425	--	--	3,425	W	--	--	W
Catalysts (oil-refining)	11,858	--	40,670	52,528	8,185	--	38,039	46,224
Face brick	--	--	--	--	--	8,895	--	8,895
Fiberglass and mineral wool	249,899	--	43,124	293,023	199,937	--	43,817	243,754
Fine china and dinnerware; crockery and earthenware	22,462	--	--	22,462	12,051	--	--	12,051
Firebrick, blocks and shapes	27,267	4,536	--	31,803	W	6,728	--	6,728
Grogs and calcines, refractory	36,495	390,027	424	426,946	W	W	W	W
Medical, pharmaceutical, cosmetic	369	--	420	789	W	--	W	W
Paint	18,757	--	199,649	218,406	19,160	--	206,716	225,879
Paper coating	--	--	2,568,846	2,568,846	54,197	--	2,698,974	2,753,171
Paper filling	229,758	--	1,312,644	1,542,402	146,957	--	1,305,658	1,452,615
Plastics	370	--	40,177	40,547	14,335	--	40,571	54,906
Pottery	26,324	--	--	26,324	24,883	--	--	24,883
Refractories4/	12,707	6,350	5,741	24,798	14,971	--	--	14,971
Roofing granules	10,143	--	--	10,143	W	W	--	W
Rubber	77,630	--	19,556	97,186	13,297	--	45,606	58,903
Sanitaryware	33,018	--	--	33,018	39,042	--	--	39,042
Miscellaneous, air-float:								
Common brick, fertilizers, gypsum products, pesticides and related products, roofing and structural tile, other uses not specified	172,726	--	--	172,726	206,655	--	--	206,655
Miscellaneous, unprocessed:								
Fertilizers, pesticides and related products, other uses not specified	--	37,624	--	37,624	--	717,756	--	717,756
Miscellaneous, water-washed:								
Gypsum products, ink, pesticides and related products, waterproofing and sealing, fertilizers, other uses not specified	--	--	147,516	147,516	--	--	162,193	162,193
Total3/	948,988	605,641	4,395,906	5,950,535	774,408	733,379	4,562,571	6,070,368
Exports:								
Paint	--	--	27,115	27,115	--	--	25,857	25,857
Paper coating	20,650	--	1,074,973	1,095,623	20,894	--	1,135,074	1,155,968
Paper filling	32,479	--	262,155	294,634	38,306	--	266,330	304,635
Refractories	--	32,540	--	32,540	--	--	--	--
Rubber	--	--	17,451	17,451	--	--	17,953	17,953
Undistributed	21,629	--	54,995	76,624	29,795	142	56,216	86,153
Total3/	74,758	32,540	1,436,689	1,543,987	88,995	142	1,501,430	1,590,566
Grand total3/	1,023,746	638,181	5,832,595	7,494,522	863,403	733,520	6,064,012	7,660,935

W Withheld to avoid disclosing company proprietary data; with "Miscellaneous".
1/Includes high-temperature calcined.
2/Includes low-temperature calcined and delaminated.
3/Data may not add to totals shown because of independent rounding.
4/Includes electrical porcelain; floor and wall tile, ceramic; flue linings; glazes, glass, and enamels; high-alumina brick and specialties; kiln furniture; refractory mortar and cement.

Table 20.--Common clay and shale sold or used by producers in the United States,1/ by State

State	1989		1990	
	Metric tons	Value	Metric tons	Value
Alabama	1,703,001	$10,388,283	1,953,519	$23,766,026
Arizona	151,358	763,412	102,519	470,140
Arkansas	627,825	1,673,881	705,467	2,799,037
California	1,919,694	21,212,742	1,888,032	22,200,901
Colorado	248,308	1,866,343	262,020	1,864,041
Connecticut and New Jersey	195,539	2,455,353	165,148	2,293,793
Florida	115,981	W	W	W
Georgia	1,606,546	6,841,777	1,546,304	7,015,259
Illinois	142,207	641,237	598,479	2,515,844
Indiana	871,179	3,835,574	1,051,703	3,272,624
Iowa	439,323	1,772,934	423,227	1,376,264
Kansas	533,099	2,699,864	625,969	4,056,062
Kentucky	716,990	3,357,200	826,205	8,282,322
Louisiana	233,992	6,114,609	368,322	1,066,295
Maine and Massachusetts	96,064	474,755	52,107	237,067
Maryland	351,464	1,882,283	338,755	1,711,599
Michigan	1,249,198	4,598,922	1,201,542	4,093,649
Mississippi	497,625	2,591,061	528,456	2,568,130
Missouri	1,048,814	3,880,428	1,064,884	5,211,884
Montana	30,176	79,887	29,741	192,682
Nebraska	224,624	879,546	227,292	1,685,241
New Mexico	27,887	70,119	27,994	74,250
New York	531,559	3,428,813	490,552	2,906,006
North Carolina	2,204,617	13,599,134	2,179,428	9,355,674
Ohio	3,296,737	10,287,176	2,320,354	9,295,572
Oklahoma	565,956	1,618,977	631,302	3,155,987
Oregon	198,889	327,479	198,889	327,479
Pennsylvania	1,035,514	4,447,350	840,646	2,899,788
Puerto Rico	136,873	310,888	147,721	W
South Carolina	931,059	2,214,064	831,763	2,076,919
South Dakota and Wyoming	196,466	865,197	162,657	775,876
Tennessee	496,514	W	482,496	W
Texas	2,203,895	11,965,200	2,106,485	13,057,548
Utah	276,299	1,799,103	277,795	1,773,740
Virginia	1,001,394	6,302,335	882,383	3,740,806
Washington	230,480	1,522,712	158,257	1,356,945
West Virginia	251,385	553,474	164,257	383,710
Other2/	105,657	3,206,571	233,168	3,968,679
Total	26,694,188	140,528,683	26,095,840	151,827,839

W Withheld to avoid disclosing company proprietary data; included with "Other."
1/Includes Puerto Rico.
2/Includes Idaho, Minnesota, New Hampshire, and North Dakota.

Table 21.--Clays sold or used by producers in the United States1/ in 1990, by use
(Metric tons)

Use	Ball clay	Bentonite	Common clay and shale	Fire clay (refractor only)	Fuller's earth	Kaolin	Total
Absorbents:							
Oil and grease	--	W	W	--	350,804	--	350,804
Pet waste absorbents	--	W	W	--	1,347,270	--	1,347,270
Other2/	W	196,684	165,184	--	W	--	362,168
Ceramics and glass:							
Catalysts (oil-refining)	--	W	--	--	W	90,772	90,772
Crockery and other earthenware	--	--	--	--	--	2,998	2,998
Electrical porcelain	22,665	--	--	--	W	16,183	38,848
Fine china and dinnerware	W	--	--	--	--	17,711	17,711
Glazes, glass and enamels	--	W	--	W	--	W	788
Mineral wool and insulation, fiberglass	--	W	--	--	--	454,131	454,131
Pottery	118,519	W	150,440	W	--	27,852	296,811
Roofing granules	--	--	102,290	--	2,887	9,114	114,291
Sanitaryware	176,809	--	--	--	--	40,947	217,755
Other2/	14,926	47,619	--	W	15,046	83,886	161,477
Chemical manufacturing	--	10,082	--	--	W	218,170	228,252
Civil engineering and sealing	11,793	181,149	598,234	--	--	584,331	1,375,507
Drilling mud	--	712,973	--	--	34,150	--	747,123
Fillers, extenders and binders:							
Adhesives	W	4,410	--	--	6,350	54,789	65,549
Animal feed	21,661	105,580	W	--	W	W	127,241
Fertilitzers	--	W	--	--	61,211	2,725	63,936
Gypsum products and wallboard	W	--	--	--	31,510	2,492	34,002
Ink	--	W	--	W	--	W	W
Medical, pharmaceutical, cosmetic	--	16,045	--	--	W	3,118	19,163
Paint	W	5,747	W	--	W	261,219	266,966
Paper coating	--	W	--	--	--	2,753,171	2,753,171
Paper filling	W	W	--	--	--	1,471,298	1,471,298
Pesticides and related products	W	8,394	W	--	167,720	50,309	226,423
Plastics	W	W	--	--	W	61,901	61,901
Rubber	W	W	--	--	W	207,733	207,733
Other2/	93,562	18,993	123,288	--	66,504	187,756	491,253
Filtering,clarifying, decolorizing Animal oils, mineral oils and greases, and vegetable oils	--	62,775	--	--	23,237	458	86,470
Desiccants	--	W	--	--	--	--	W
Floor and wall tile:							
Ceramic	158,325	11	212,665	--	--	13,816	384,817
Quarry tile	W	--	530,662	--	--	--	530,662
Other2/	W	--	--	--	--	29,946	29,946
Heavy clay products:							
Brick, extruded	W	W	10,540,509	17,822	--	256,724	10,815,055
Brick, other	--	--	1,837,495	--	--	33,987	1,871,482
Drain tile	--	--	9,604	--	--	--	9,604
Flower pots	--	--	68,026	--	--	--	68,026
Flue linings	--	--	22,140	5,842	--	W	27,982
Portland and other cements	--	W	7,095,811	--	--	176,003	7,271,814
Roofing tile	--	W	W	--	--	--	W
Sewer pipe, vitrified	--	--	107,986	227	--	W	108,213
Structural tile	--	--	54,122	--	--	--	54,122
Terra cotta	--	--	W	--	--	--	W
Other2/	W	5,177	96,439	2,098		32,168	135,882
Lightweight aggregate:							
Concrete	--	--	2,523,507	--		--	2,523,507
Highway surfacing	--	W	267,861	--		--	267,861
Structural concrete	--	--	786,084	W		--	786,084
Other2/	--	7,194	226,879	W		--	234,073
Pelletizing iron ore	--	682,878	W	--	--		682,878
Refractories:							
Firebrick, blocks, and shapes	W	W	98,321	453,024		134,927	686,272
Foundry sand	--	864,680	--	7,739		536	872,955
Grogs and calcines	--	--	--	20,208		759,246	779,454
Highalumina brick and specialties	--	--	--	41,192		W	41,192
Kiln furniture	15,814	W	--	--		W	15,814
Mortar and cement, refractory	852	--	407,145	--		--	407,997
Other2/	W	49,386	W	44,469	34,948	41,108	169,907
Other3/	62,167	31,039	52,538	23,822	23,629	10,799	203,993
Exports	90,570	462,483	18,606	9,364	140,210	1,669,515	2,390,748
Total	787,663	3,473,595	26,095,808	625,808	2,307,476	9,761,775	43,052,152

W Withheld to avoid disclosing company proprietary data; included with "Total" and/or "Other".
1/Includes Puerto Rico.
2/Includes uses indicated by symbol W.
3/Uses not specified.

Table 24.--Common clay and shale used in lightweight aggregate production in the United States, by State

State	Metric tons					
	Concrete block	Structural concrete	Highway surfacing	Other	Total	Total value
1989						
Alabama and Arkansas	487,191	85,411	11,301	10,705	594,608	$4,679,265
California	67,813	42,698	--	--	110,511	913,596
Florida and Indiana	213,345	26,082	--	--	239,427	1,539,773
Kansas, Kentucky, and Louisiana	218,632	92,533	10,886	53,506	375,557	7,222,558
Mississippi	49,137	5,830	8,330	111,018	174,315	1,483,883
New York	215,239	140,527	--	--	355,766	2,489,218
North Carolina	230,000	80,000	--	--	310,000	3,200,000
Ohio, Oklahoma, and Pennsylvania	240,244	14,000	2,386	--	256,630	727,340
Texas	98,791	236,232	288,240	--	623,263	2,595,150
Utah and Virginia	246,088	49,739	5,738	40,020	341,585	3,493,119
Total	2,066,480	773,052	326,881	215,249	3,381,662	28,343,902
1990						
Alabama and Arkansas	707,627	85,121	11,336	--	804,084	9,732,809
California	78,131	98,727	--	--	176,858	656,295
Florida and Indiana	254,153	29,484	--	--	283,637	1,752,382
Kansas, Kentucky, and Louisiana	245,984	228,661	14,646	67,303	556,594	1,579,347
Mississippi and Missouri	127,793	10,777	15,397	118,606	272,573	1,569,533
New York and Montana	259,283	40,823	--	--	300,106	1,876,954
North Carolina	244,940	81,647	--	--	326,587	3,319,616
Ohio, Oklahoma, and Pennsylvania	246,209	37,145	1,102	--	284,456	1,826,995
Texas	65,596	156,943	222,260	30,844	472,643	2,284,427
Utah and Virginia	296,791	16,756	3,120	10,126	326,793	1,635,545
Total	2,523,507	786,084	267,861	226,879	3,804,331	26,233,903