Geology of the Southeastern Bauxite Deposits

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BAUXITE DEPOSITS OF THE SOUTHEASTERN UNITED STATES

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Distribution, occurrence, and resources of bauxite

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By Elizabeth F. Overstreet

ABSTRACT

Bauxite deposits in the Southeastern United States are mainly restricted to the Coastal Plain and the Valley and Ridge physiographic provinces. The deposits are in Georgia, Alabama, Tennessee, Virginia, and Mississippi, in that order of importance. They are scattered across the region in 15 districts. Bauxite has been mined continuously since 1888, and total production has been about 2,567,500 long dry tons. Reserves of commercial bauxite in the Southeastern United States amount to about 1,055,000 long tons, somewhat less than 1½ percent of total reserves of bauxite in the United States.

Bauxite formed during the Paleocene-Eocene interval on a land surface which extended inland from the strand line and up the Appalachian Valley at least as far as northern Virginia. The parent material was a fine-grained sediment probably consisting of clay, feldspar, other silicates, and a few heavy minerals indicative of metamorphic rocks. Clay and fine-grained detritus, separated from a more generally coarse-grained sequence, accumulated in lakes, ponds, and shallow karst depressions in the aggrading area. Bauxite was formed when the parent material was exposed by erosion in well-drained localities such as on hills or slopes or in shallow well-drained sinkholes. Surficial weathering produced bauxite by a process of leaching common in humid tropical regions. Bauxite was preserved where it was covered by sediments of later Eocene or Oligocene age or where it was redeposited at lower levels in deepened sink holes. Elsewhere, most of it has since been removed.

INTRODUCTION

This introductory chapter is a summary of investigations of bauxite deposits in the Southeastern United States (pl. 1). The investigations were conducted by the U.S. Geological Survey during and after World War II as part of a search for new bauxite deposits and an evaluation of resources in the United States. Reports on the individual areas and districts were made by Survey geologists and have been prepared for publication by E. F. Overstreet. The bauxite deposits occur in Georgia, Alabama, Tennessee, Virginia, and Mississippi. Most deposits, and all the large ones (pl. 1, districts 1–3, 5–8, 10, and 12–24), are in the Coastal Plain and Valley and Ridge physiographic provinces as outlined by Fenneman (1938). Small deposits occur in the Piedmont province (pl. 1, district 9) and in the Interior Plateau province (pl. 1, districts 11 and 4); however, all these deposits are in small outliers of Coastal Plain sedimentary rocks.

A large number of deposits in a distinct geographic locality are referred to as a district. Some large districts that extend over several counties are subdivided into areas. The locations of all districts and areas are shown on plate 1.

Field work included in a large-scale drilling program that was conducted jointly by the U.S. Geological Survey and the U.S. Bureau of Mines. The work of the Geological Survey consisted primarily of geologic mapping, of making drilling recommendations, of determining locations of holes and depths to which they were drilled and the depths to be cored, and, in part, of logging the holes. The work of the Bureau of Mines consisted primarily in arranging for and conducting the drilling, sampling, mapping locations of holes, and making all chemical analyses of bauxite and associated clay.

ACKNOWLEDGMENTS

The work reported in this bulletin was done under the general direction of the late Josiah Bridge. The authors of all chapters are indebted to him for many of the broad concepts of distribution and origin of bauxite (Bridge, 1950, p. 170–201) which established guidelines for the work.

Companies and individuals in the region gave very freely of their information on outcrops, test pits, and drilling and are here warmly acknowledged. The State Geologists and their staff members, and geologists of the Tennessee Valley Authority were also most cooperative in supplying chemical analyses, locations, and other information on deposits in their States. It is also a pleasure to acknowledge the cooperation and the cordial relations that marked the exploratory drilling program conducted jointly by the Bureau of Mines and the Geological Survey.

DISCOVERY AND DEVELOPMENT

Bauxite was first discovered in the United States in 1860 by E. W. Hilgard at a locality near Blue Mountain, Tippah County, Miss., but he did not recognize his rock to be bauxite. Hilgard, (1860, p. 14) described what he found as "a singular rock * * * resembling a true pudding stone." The first recognition of bauxite in the United States was by Edward Nichols, President and Acting Chemist of the Ridge Valley Iron Co., who announced his discovery at an anuual meeting of the American Institute of Mining Engineers in 1887 (Nichols, 1888, p. 905–906). His identification of "beauxite" was made from a sample of dark-red pisolitic rock found by James Holland on his property in Floyd County, northwestern Georgia. Holland believed the bauxite to be a peculiar variety of iron ore (Watson, 1904, p. 25). The exact date of discovery is somewhat uncertain. Litchfield (1941, p. 155) gave the date as 1883, and this is further elucidated by Bridge (1950, p. 174) who stated that, in correspondence with him, Litchfield cited company letters written by Nichols in 1883 mentioning "beauxite." Unauthenticated reports (Mining World, 1905, p. 89) gave the discovery date as early as 1881, but this date appears to be too early, although it could conceivably be the time Holland became curious about the outcrop of pisolitic rock.

Mining followed rapidly on discovery and began in April 1888 at the Holland property (Watson, 1904, p. 25). The first shipments of bauxite were made the following year. Bauxite was discovered in nearby Cherokee County, Ala., in 1889 (McCalley, 1892, p. 20). Within the next few years many additional deposits were discovered in the Valley and Ridge province of Alabama and Georgia, and high-grade deposits were soon exploited. The Republic Mining and Manufacturing Co. was the first company to mine in each State, and by 1894 the Georgia Bauxite Co. and the John D. Taylor Bauxite Co. were mining in Georgia, and the Southern Bauxite Mining and Manufacturing Co. was active in Alabama (McCalley, 1894, p. 29–30).

The remaining major discoveries in the region were all made by 1922. Deposits in the Chattanooga district, Tennessee, were discovered in 1906. In 1909 bauxite was found for the first time in the Coastal Plain province, in Wilkinson County, Ga., a fact that opened up a whole new area of search. Andersonville, Ga., the largest district in the region, was discovered in 1912. Two small districts, Warm Springs and Springvale, Ga., were discovered in 1915 and 1916, respectively. The last large district in the region was discovered near Eufaula, Ala., in 1922. In the following two decades a few small districts or isolated occurrences were discovered, but they are of minor importance.

PRODUCTION

Bauxite production in the Southeastern States from 1889 through 1960 amounted to a total of 2,567,500 long tons, dried basis. Of this total, the author estimates from records in the Geological Survey and Bureau of Mines that Georgia produced about 1,230,100 long tons and Alabama about 1,230,700 long tons. The total for these two States is 96 percent of production in the Southeastern States. About 3 percent of the remaining bauxite produced came from Tennessee, about 1 percent from Virginia, and a negligible tonnage from Mississippi.

Past production from the region can best be discussed briefly by 10- or 20-year periods. Production data are from annual volumes of Mineral Resources of the United States by the U.S. Geological Survey (1890–1924) and the Minerals Yearbook by the U.S. Bureau of Mines (1925–1960). Unless otherwise specified, all figures are in long tons and on a dried basis. Production from the Southeastern States, total United States production, and imports from 1889 through 1960 are shown on figure 1.

From 1889 through 1909, a 21-year period, all production in the Southeastern States came from the Valley and Ridge province of Georgia, Alabama, and Tennessee. Shipments of bauxite began in Georgia in 1889, in Alabama in 1891, and in the Chattanooga district, Tennessee, in 1907. A total of 377,549 long tons of bauxite was produced during the period.

The decade from 1910 through 1919 was a period of increased production, in part due to great demands during World War I and in part to new discoveries, chiefly in the Georgia Coastal Plain province. Mining began in the Coastal Plain in 1910 in the Irwinton district; three years later the large Andersonville district was in production. Mining also began in three small districts—Elizabethton, Tenn., and Warm Springs and Springvale, Ga. Total production in the Southeastern States from 1910 through 1919 amounted to 404,442 long tons.

The decade of the 1920's was marked by the closing of many mines and districts, and many companies ceased operations, but it was also the period when the Eufaula district, Alabama, was discovered and came into production. By 1929, only the two largest districts, Andersonville, Ga., and Eufaula, Ala., were in operation. Production from 1920 through 1929 in the region amounted to a total of 238,378 long tons.

The period from 1930 through 1939 was very similar to that in the later 1920's except that activities began to increase somewhat toward the end of the period. Total production in the Southeastern States for the decade amounted to 134,787 long tons, little more than half that of the previous 10-year period and about a third of that from 1910 through 1919.

In the early 1940's, production in the Southeastern States increased sharply because of increased demands during World War II; but it had again decreased by the end of the decade. One small new district, Spottswood, Va., in the Valley and Ridge province was opened. Bauxite was mined in the Eufaula and Andersonville districts as well as in the Northeast Alabama and Northwest Georgia districts and in Mississippi. Other districts were inactive in spite of unprecedented demand for bauxite. By 1949, mining had ceased in Virginia, northeastern

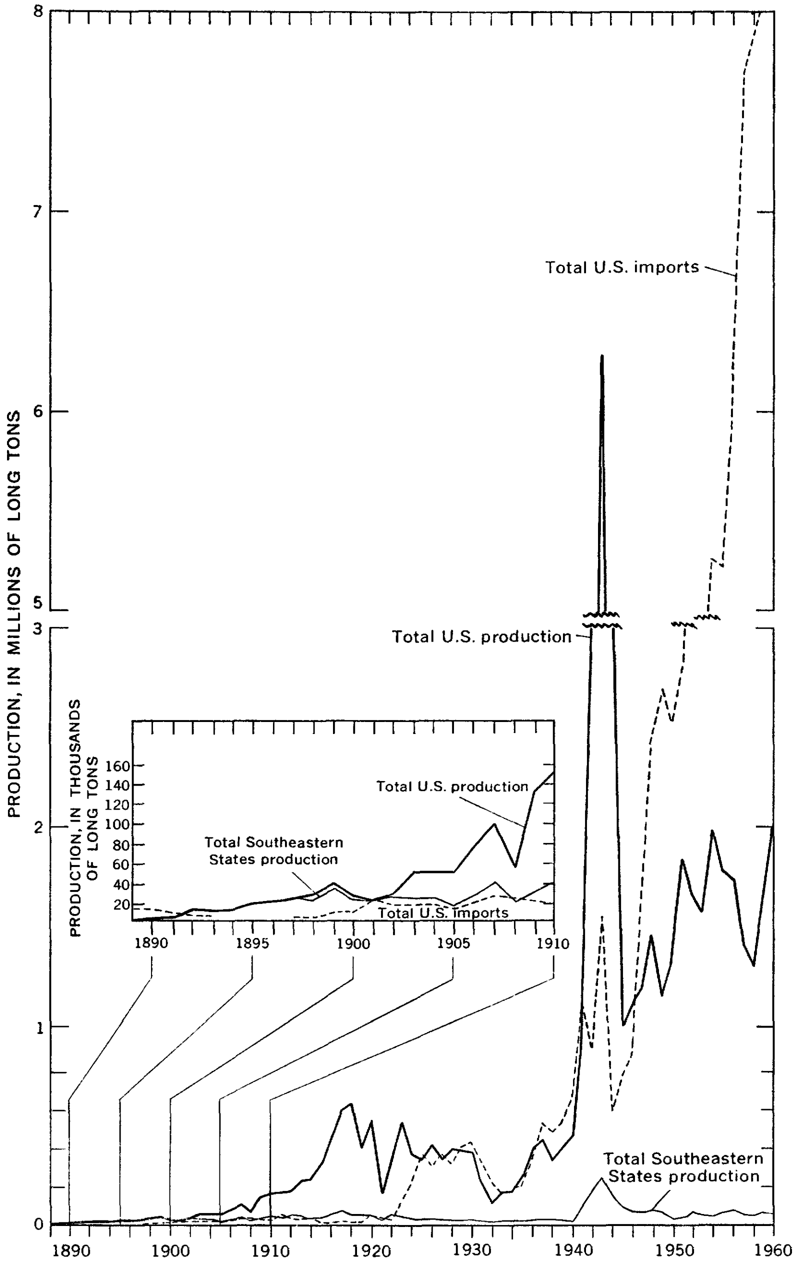

FIGURE 1.—Bauxite production in the United States, production in the Southeastern States, and imports, by years, 1889–1960. Data from annual volumes of Mineral Resources of the United States (Geological Survey) and the Minerals Yearbook (Bureau of Mines). Production figures are in long tons.

Alabama, and Mississippi. Total production in the five States, 1940–49, amounted to 815,551 long tons.

From 1950 through 1960, bauxite was mined in the Southeastern United States only in Alabama and Georgia. Five companies operated during parts of the period. Only the American Cyanamid Co. was active in Georgia, but it operated mines in both the Northwest Georgia and the Andersonville districts. Bauxite mining in Alabama was restricted to the Eufaula district, and the following companies were active: Aluminum Company of America (abbreviated Alcoa; formerly the Republic Mining and Manufacturing Co.), D. M. Wilson Bauxite Co., R. E. Wilson Mining Co., and Harbison-Walker Refractories Co. In 1955, Alcoa sold its mine and drying plant to the newly formed R. E. Wilson Mining Co. and ceased mining in the region. This terminated 66 years of continuous operation by Alcoa in the Southeastern States. Harbison Walker is the latest company to enter the field and began mining in 1959. Total production in the Southeastern States 1950 through 1960, an 11-year period, amounted to 612,105 long tons.

IMPORTANCE OF THE REGION

The first bauxite mined in the United States came from the Southeastern States, and for more than a decade the region was the primary source of ore. However, its relative position declined in 1903, and Arkansas became the leading producer. Reserves large enough for the region to regain leadership were never found despite the discovery of many new deposits. An almost 20-fold increase in bauxite imports between 1940 and 1960 further dwarfed production from this part of the country (fig. 1).

The Southeastern region supplies a minor but important part of the bauxite consumed in the United States. Because of its low iron content, the bauxite from this region is chiefly used in making refractories and chemicals; minor amounts are used in the manufacture of abrasives and for water purification and petroleum refining. None of this bauxite is used in the manufacture of aluminum. The bauxite used by the chemical and refractory industries in the United States in 1959 amounted to about 320,000 long dry tons (Wilmot and others, 1960, p. 226). Total bauxite production from the Southeastern States amounted to about 69,000 long dry tons for the same period or about one-fifth of the bauxite used by these two industries alone. The bauxite resources in the Southeastern States are important as a source of low-iron aluminous materials, but they are not large enough to provide significant amounts of ore for the aluminum industry.

GEOLOGIC SETTING

The distribution of bauxite deposits in the Southeastern United States is controlled by several geologic factors which combine to produce the greatest concentration of deposits in adjacent parts of Alabama and Georgia. The most important factors are (1) presence of a large area of crystalline rocks, (2) formation on an ancient land surface, and (3) preservation of bauxite and kaolin from erosion.

Most of the bauxite deposits of the region, and all of the commercially important ones, are in a belt which bounds the northwest, south, and southeast sides of a large area of crystalline rocks (pl. 1). The belt is less than 40 miles wide except at its south end where bauxite is about 75 miles from crystalline rocks. Along the northwest side of the crystalline rocks, the belt is in the Valley and Ridge province and extends from Virginia through Tennessee and Georgia to Alabama. Along the south and southeast sides, the belt is in the Coastal Plain province and extends from eastern Alabama to central Georgia and probably originally extended northeastward into South Carolina.

Small and low-grade bauxite deposits are scattered across the western part of the Southeastern States region, and the association of these deposits to the crystalline rocks is less clear because of distance and an incomplete knowledge of early Tertiary drainage patterns. A belt of small and low-grade deposits occurs in sedimentary rocks of Paleocene and Eocene age in Mississippi, and bauxite in isolated outliers of Tertiary and Cretaceous sedimentary rocks in northwestern Tennessee and northwestern Alabama have been preserved in sinkholes.

Bauxite deposits in the Southeastern United States were formed on a Paleocene and Eocene land surface, which sloped gently toward the early Tertiary Gulf of Mexico, and on the extension of this surface up the Mississippi Embayment. In the Coastal Plain province, the surface extended inland from the strand line as far as the "inner line" of deposits (pl. 1). In the Valley and Ridge province, this surface was represented by a peneplain referred to as the Harrisburg or Valley Floor peneplain by Bridge (1950, p. 197). The surface was formed on Cambrian and Ordovician carbonate rocks which compose the floor of the Appalachian Valley. The surface probably did not occur everywhere as featureless plains but included low hills and ridges. If so, erosion and stream deposition were active.

The preservation of bauxite deposits from erosion is an important factor in their present distribution. Within the Appalachian Valley, preservation is mainly due to redeposition of bauxite and kaolin below the surface by collapse of underlying caverns in limestone geologically soon after its formation. Present distribution of deposits is restricted to fortuitous location near present-day divides or on remnants of old terraces. In the Coastal Plain, solution of thin limestone also lowered some deposits, which were thus protected from erosion, but the most important factor was burial by younger strata. The districts with largest deposits are those in which burial was early and followed by only minor erosion.

Undoubtedly, bauxite deposits were once much more abundant than at present. The removal of bauxite during the present erosion cycle is indicated by truncated deposits in hillsides and valleys and by the occurrence of large deposits only in protected areas. Erosion of bauxite in preceding cycles, particularly penecontemporaneous erosion, is indicated by truncated and channeled deposits and reworked bauxite and kaolin fill in channels.

BAUXITE AND KAOLIN IN THE COASTAL PLAIN PROVINCE

The bauxite and related kaolin deposits in the Coastal Plain province are associated with sedimentary rocks of Paleocene, Eocene, and Cretaceous ages. The correlation of sedimentary rocks in the bauxite districts is shown in figure 2. The deposits in rocks of Paleocene and Eocene age are located along a discontinuous arc which Bridge (1950, p. 186) designated the "outer line" (pl. 1). This arc passes through northeastern Mississippi, southern Alabama, and southwestern Georgia. The deposits associated with rocks of Cretaceous age are also alined in a belt, referred to as the "inner line." This line lies 50 to 100 miles from the "outer line" and passes through northwestern Tennessee, northwestern Alabama and central Georgia. Many of the deposits along the "inner line" are in outliers of sedimentary rocks that underlie the Coastal Plain (pl. 1).

The period of bauxite formation was a short one, beginning no earlier than late Paleocene and ending in the early Eocene. This period is referred to as the Paleocene-Eocene interval. It is dated in the Coastal Plain by the stratigraphic position of bauxite deposits along the "outer line." These deposits are formed on rocks of late Paleocene and very early Eocene age and are overlain by strata of early Eocene age. Bauxite deposits on rocks of Cretaceous and early Tertiary age farther inland along the "inner line" were doubtless formed during this same interval, as first suggested by Bridge (1950, p. 186–188).

In Mississippi, bauxite and associated kaolin occur at the top of the Porters Creek Clay of Paleocene age and at the base of the overlying Fearn Springs Sand Member of the Wilcox Formation of early Eocene age. The bauxite and kaolin at the top of the Porters Creek Clay grade downward through white micaceous clay into dark-gray mica-

Age	Group	West Tennessee Indian Mound district	Northwest Alabama Margerum district	Mississippi All districts	Eastern Alabama Eufaula district	Western Georgia Springvale and Andersonville districts	Central Georgia: Irwinton district	Central Georgia: Warm Springs district
EOCENE	Jackson				Jackson Group	Jackson Group	Jackson Group	
EOCENE	Claiborne				Claiborne Group	Claiborne Group	Claiborne Group	
EOCENE	Wilcox	? Clay of probable Paleocene and Eocene age	? Clay of probable Paleocene and Eocene age	Wilcox Formation Fearn Springs Sand Member	Bashi Marl Member of Hatchetigbee Formation Tuscahoma Sand Nanafalia Formation	Bashi Marl Member of Hatchetigbee Formation Tuscahoma Formation Nanafalia Formation		
PALEOCENE	Midway	?	?	Porters Creek Clay Clayton Formation	Clayton Formation	Clayton Formation		
LATE CRETACEOUS	Selma			Prairie Bluff Chalk and Owl Creek Fm Ripley Formation	Providence Sand Ripley Formation	Providence Sand Ripley Formation	Upper Cretaceous rocks, undifferentiated	Upper Cretaceous rocks, undifferentiated
LATE CRETACEOUS	Tuscaloosa	Sand and gravel, probably equivalent to Gordo Formation	Gordo Formation					
MISSISSIPPIAN		Warsaw Limestone	Cypress Sandstone Gasper Formation Bethel Sandstone Ste. Genevieve Limestone equivalent Warsaw Limestone					

FIGURE 2.—Correlation chart of formations exposed in bauxite districts of the Coastal Plain and outliers of Coastal Plain rocks.

ceous clay which makes up most of the formation. The kaolin and bauxite may have formed from the dark-gray clay by weathering and reworking, but probably the clay which originally constituted the upper part of the formation in the bauxite areas was different from most of the formation; it probably represented a shoreward facies of the Porters Creek Clay. The Porters Creek Clay is characteristically highly montmorillonitic, but in the vicinity of bauxite deposits, which is also the up-dip edge of the formation, both the white and the dark micaceous clays are kaolinitic. Much of the bauxite and kaolin in the overlying Fearn Springs Sand Member is in channel-fill deposits. Some of the kaolin is fragmental, and clay spars and balls are common. Impure lignite beds and stringers are found in the kaolin at many places. The channel-fill deposits have been transported.

In the Eufaula district, Alabama, and the Springvale and Andersonville districts, Georgia (pl. 1), bauxite and kaolin are restricted to the lower part of the Nanafalia Formation of early Eocene age. They are underlain by, and grade laterally into, sand characteristic of the bulk of the formation. The Nanafalia Formation in these districts is underlain by the Clayton Formation (Paleocene), which is chiefly a marine limestone. The bauxite and kaolin deposits, although dislocated by solution of the limestone, commonly are broad, somewhat undulating, and relatively thin compared to their breadth. Deposits were more extensively preserved in the Eufaula and Andersonville districts than elsewhere in the region because of an early cover of terrestrial beds of the upper part of the Nanafalia Formation.

No bauxite is present in the Paleocene and lower Eocene Formations in the broad area extending from the Eufaula district in eastern Alabama to the Winston-Noxubee-Kemper district, Mississippi (pl. 1), approximately 40 miles west of the Alabama boundary. These formations are marine in this area and were apparently deposited in a shallow bay that extended farther north than their present outcrop belt. No evidence of the shoreline remains, and if bauxite ever was present along the margins of the bay, it has been removed by erosion.

Bauxite and kaolin in the Margerum district, Alabama, and Indian Mound district, Tennessee, along the northwestern part of the "inner line," fill sinkholes in limestone of Mississippian age. The present-day surface in each district is largely covered by an unconsolidated sand and gravel known in the Margerum district as the Gordo Formation of Late Cretaceous age and in the Indian Mound district considered to be a probable equivalent of the Gordo. In both districts bauxite and kaolin are part of a unit which overlies the rocks of Cretaceous age. The bauxite-bearing unit consists largely of sand, impure clay, and lignite. Spores from the lignite in the Indian Mound district were determined by E. S. Barghoorn (Wilson, 1953, p. 761) to be post-Cretaceous to pre-Miocene in age. The bauxite and kaolin are present only as erosional remnants. They are probably similar to the kaolin in Carroll County, Tenn., described by Whitlatch and Gildersleeve (1946). There kaolin, interbedded with sand and lignite, fills a broad shallow depression and is overlain by formations of early Eocene age. The bauxite deposits in the Margerum and Indian Mound districts are remnants of terrestrial beds that probably were not continuous over a broad area.

Bauxite and kaolin in the Warm Springs and Irwinton districts, Georgia, along the eastern part of the "inner line," are underlain by unconsolidated sand and clay of Late Cretaceous age. In the Warm Springs district, the sand and clay are a small remnant of sedimentary rocks infolded into schists of the Piedmont province, and the bauxite deposit has the shape of a steeply dipping vein. No younger overlying sediments are present. In the Irwinton district, the entire Upper Cretaceous is represented by an undifferentiated sequence of sand, gravel, and kaolinitic clay. Bauxite occurs in nonsandy kaolin at the top of the sequence, but kaolin beds occur throughout. Formations of middle and late Eocene age and Oligocene age overlie the bauxite.

Pisolitic bauxite or pisolitic clay has been reported from localities along the Cretaceous-Tertiary contact as far northeast of the Irwinton district as Columbia, S.C. The pisolitic material in South Carolina occurs sporadically as reworked boulders at the base of the Congaree Formation of Eocene age (Cooke and MacNeil, 1952, p. 23) and at the base of Tertiary beds undifferentiated (Pooser and Johnson, 1961). Large deposits of bauxite or pisolitic kaolin, however, are not known northeast of the Irwinton district, Georgia.

BAUXITE AND KAOLIN IN THE VALLEY AND RIDGE PROVINCE

Bauxite deposits in the Valley and Ridge province extend from Virginia southwestward into Tennessee, Georgia, and northeastern Alabama (pl. 1). Most of the deposits are at the south end of the province in adjacent parts of northern Alabama and Georgia, and the relative abundance of deposits decreases to the north. With minor exceptions, deposits are in areas underlain by carbonate rocks of the Knox Group or its equivalent of Late Cambrian and Early Ordovician age. They appear to have filled ancient sinkholes in the carbonate rocks.

Bauxite districts and areas occupy relatively high topographic localities on the irregular floor of the Appalachian Valley. Most districts or areas are along the divides between major streams or are in the upper reaches of tributaries. A few districts and areas are on terrace remnants of probable early Tertiary age considerably above present stream level.

The surface on which the bauxite formed and to which the sinkholes are related is the Harrisburg or Valley Floor peneplain, as pointed out by Bridge (1950, p. 191–193). The peneplain was formed on carbonate rocks of the valley floor. It was probably a much less dissected surface than the present Appalachian Valley, as suggested by the presence of bauxite and kaolin deposits at or only slightly above stream level in districts which are near the heads of streams but considerably above stream level on terraces in districts adjacent to large rivers.

The age of the bauxite deposits in the Valley and Ridge province is considered to be Paleocene and Eocene chiefly on the basis of fossil plants collected from kaolin associated with bauxite and from kaolin in geologic settings similar to the bauxite. Identifiable plants were collected from kaolin associated with bauxite in a pit near Cedartown, northwestern Georgia, and from kaolin deposits in the Anniston and Fort Payne areas, northeastern Alabama (Cloud and Brown, 1944, p. 1466). The flora from these three localities is considered to be of Midway (Paleocene) or early Wilcox (early Eocene) age and to have strong Cretaceous affinities (Bridge, 1950, p. 194). No fossils have been found in bauxite, and no plant remains could be expected to survive the severe weathering conditions that formed the deposits. The assumption that the kaolin and bauxite are of the same age, however, appears valid because of the close genetic relationship between the two types of deposits.

DESCRIPTION OF DEPOSITS

Bauxite deposits in the Southeastern States are small, scattered, discrete pods separated by barren sand or sandy clay areas. Deposits commonly consist of one or more centers or kernels of bauxite surrounded by lower-grade bauxite or bauxitic clay that, in turn, grades rather abruptly into kaolin. In the Coastal Plain deposits, kaolin grades outward through sandy kaolin into light-colored sand or sandy clay, but in the Valley and Ridge province, the kaolin is in sharp contact with the surrounding red sandy clay.

In the Coastal Plain, bauxite and kaolin deposits are broad and undulating and thicken and thin over irregularities in the underlying beds. Local relief of the upper surface of underlying beds is as much as 100 feet. The bauxite tends to be concentrated in both topographic highs and lows. The concentration in the lows appears to result from lowering of bauxite due to solution of the underlying limestone or from filling of channels cut during a late stage of erosion. The concentrations on highs are presumably preserved parts of the surface on which bauxite was formed. The bauxite on highs is commonly undisturbed and in the lows has been transported, a conclusion supported by textural differences. Fragmental bauxite and kaolin are most common in the lows; pisolitic bauxite occurs in both highs and lows, but nonpisolitic bauxite is more common on highs than elsewhere.

Bauxite and kaolin deposits in the Valley and Ridge province are commonly cone shaped in section but may be elongate parallel to the local joint pattern or may be irregular in shape. In places, two or more deposits coalesce, and locally several deposits are alined along a fault or conspicuous joint. They range in size from a few feet to several hundred feet in length, and most have greater depth than width. Evidence of slump after bauxite was formed is indicated by small slickensides, particularly in the kaolin, and by intermixing of displaced masses of different types of bauxite. Locally, blocks of pisolitic bauxite, a foot to 10 feet on a side, are surrounded by kaolin; blocks of kaolin are enclosed by bauxite; and parts of the bauxite consist of bedded and size-graded pisolites with or without a matrix.

Bauxite and kaolin are characteristically very light gray to very light buff. A few deposits, or parts of deposits, are red, largely owing to secondary enrichment of iron by surface and ground water.

Most bauxite is pisolitic. Pisolites range in size from about 2 mm to 3 cm or more in diameter. The smaller ones are commonly nearly spherical and consist of concentric layers around a single center which may be solid, filled with spongelike fine-grained vesicular material, or empty. The larger pisolites are compound and irregularly shaped and consist of many small pisolites enclosed by an outer concentric shell. Both single and compound pisolites occur in the same deposit. Small- and medium-sized pisolites may lack a matrix, but large pisolites nearly everywhere are in a matrix, which commonly has a claylike texture. Some bauxite is nonpisolitic and variable in appearance, from claylike material to crumbly, somewhat vesicular soft material. In places the bauxite is fragmental. The "granitic" texture common in bauxite overlying syenite in Arkansas is not present.

MINERALOGY

Gibbsite, γ-$Al(OH)_3$ or alumina trihydrate, is the chief bauxite-forming mineral throughout the Southeastern States. Boehmite, γ-$AlOOH$, the γ-monohydrate, has been found in small quantities in five localities in the region, but it is rare. Diaspore, α-$AlOOH$ or $AlHO_2$, the α-monohydrate, has not been detected in bauxite deposits in the region.

The most important impurity in bauxite of the Southeastern States is kaolinite, $(OH)_8Si_4Al_4O_{10}$, also written $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$. Small amounts of halloysite, $(OH)_8Si_4Al_4O_{10}$, but no other clay minerals, were detected in samples of bauxite and associated kaolin investigated by X-ray and differential thermal analysis methods.

Accessory minerals in bauxite commonly include some of the following: magnetite, maghemite, hematite, goethite, limonite, siderite, chamosite, pyrite, ilmenite, rutile, leucoxene, zircon, tourmaline, kyanite, and very rarely quartz. Secondary enrichment of iron in some deposits has resulted in a high content of goethite, siderite, hematite, or chamosite.

The red residual clay which surrounds bauxite and kaolin deposits in the Valley and Ridge province contains large amounts of illite, montmorillonite, and mixed-layer clay minerals, as well as kaolinite. It also contains variable but appreciable amounts of quartz.

GEOLOGIC HISTORY AND ORIGIN

In the Coastal Plain, marine deposition in Paleocene time ended with regional uplift. Earliest Eocene deposits were nonmarine in the bauxite districts and marine in central and western Alabama and elsewhere down the dip. The nonmarine beds, like the nonmarine beds of Cretaceous age, consist of sorted and unsorted detritus, largely sand, sandy clay, and clay—commonly kaolin. During both the Eocene and the Cretaceous, clay and fine-grained detritus, partly arkosic, accumulated in abandoned channels, lakes, and other areas that were periodically flooded. Intraformational channels indicate that the surfaces of the deposits were continuously modified as the deposits were built up.

In the Appalachian Valley during the Paleocene-Eocene interval, clay and other fine-grained detritus probably accumulated in shallow sinkholes. This fine-grained material later weathered to bauxite which was similar to bauxite now filling karst depressions in Jamaica (Zans, 1953, p. 318), Haiti, and the Dominican Republic (Goldich and Bergquist, 1947, 1948). The amount of residuum remaining on the carbonate rocks in the Appalachian Valley at this period and the amount, if any, that weathered to bauxite are unknown; however, the following two observations suggest that most of the surface was bare when the detritus accumulated in the sinkholes: (1) The present residuum is a variable but sandy red clay which would require the removal of large quantities of silica and iron and a change in the clay mineralogy to form kaolin and bauxite and (2) the absence of red residual clay mixed with blocks of white bauxite or kaolin filling sinkholes suggests that the red clay was not present at the time the bauxite and kaolin collapsed into the sinks.

In the Southeastern States, the parent material from which bauxite was formed was a transported sediment which contained heavy minerals, indicative of metamorphic rocks as the ultimate source rock. Because heavy minerals are present in bauxite and associated kaolin, the parent material must have been transported, not entirely as a clay, but partly as a coarser grained material, probably a fine-grained clayey arkose. Feldspar and certain other silicates may have been concentrated with clay because they probably occurred in smaller grains than quartz, owing to their lower resistance to weathering.

The bauxite deposits in the Southeastern States appear to have formed under subaerial conditions in a humid tropical climate. A worldwide change to a warm humid climate began in Late Cretaceous time and reached a peak during the Paleocene and early part of the Eocene Epochs (Durham, 1950, p. 1253–1254; Reid and Chandler, 1933, p. 47–74). During this period, all climatic zones shifted markedly poleward, and temperate deciduous forests extended to within the Arctic Circle (MacGinitie, 1958, p. 64). The climate remained generally warm and humid until the end of Oligocene time, when it became progressively cooler and, in places, drier. The cooling trend culminated in the vast climatic oscillations of the Pleistocene glacial period. Paleobotanical evidence that a tropical climate existed in the Southeastern States during Paleocene and Eocene time has been presented by Barghoorn (1951, p. 736–744), MacGinitie (1958, p. 64–66), and Berry (1930, p. 40). The fact that the early Tertiary climate was warm and humid supports the hypothesis that bauxite forms only under such conditions and that bauxite formation in the Southeastern States was restricted to a single period, the Paleocene-Eocene interval. The occurrence of bauxite of early Tertiary age in Great Britain, parts of central and southern Europe, and Russia is also explained by this period of warm and humid climate, as is the fact that at present formation of bauxite has been recognized only in the tropics.

Bauxite in the Southeastern States was probably formed by weathering processes similar to those described in Indonesia (Mohr, 1933), British Guiana (Harrison, 1911a, 1911b, and 1934), Guinea (Lacroix, 1913), the Palau Islands (Bridge and Goldich, 1948), and Arkansas (Goldman and Tracey, 1946; and Gordon, Tracey, and Ellis, 1958). The conditions in the Southeastern States appear to be very similar to those described in Arkansas, where bauxite also formed during the Paleocene-Eocene interval. According to Gordon, Tracey, and Ellis (1958, p. 145–146), these conditions were (1) a climate in which rainfall considerably exceeds evaporation most of the time, (2) temperature exceeds 77°F (25°C) most of the time, (3) pure rainwater acts on an aluminous parent material, (4) the parent material is in a well-drained locality, above the permanent water table, and (5) the conditions last for a considerable period of time.

Bauxite was formed in the Southeastern States from masses of clay and fine-grained detritus at times when these masses happened to be exposed by intraformational erosion on hills or slopes or in shallow drained sinkholes or other karst depressions above the water table. Good subsurface drainage was provided by porous sandy beds in the Coastal Plain and by jointed limestones in the Valley and Ridge province. Gibbsite formed first at the top of the deposits, probably by the breakdown of aluminum silicates, the removal of silica in solution, and the crystallization of gibbsite in place. Pisolitic and other concretionary structures suggest solution and redeposition of gibbsite about nuclei. Concentric layers are distinguished by color variations which are due to minor differences in iron content.

The kaolin that overlies bauxite deposits has probably been derived from two sources, both later than the formation of bauxite. Some of the kaolin was eroded and redeposited above bauxite in adjacent lower parts of the same deposit. This process was active wherever the surface of bauxite was undulating, but its results are most recognizable where parts of deposits were let down into either deep or shallow sinkholes. The second source of kaolin is from the silication, or resilication, of bauxite at the tops of deposits. In this process, silica in solution evidently combines with gibbsite to form kaolinite. Effects of silication in the Southeastern States have been described by Allen (1952, p. 677–679) and in other regions by Harrison (1934, p. 9), Goldman and Tracey (1946, p. 567–573), and Gordon, Tracey, and Ellis (1958, p. 148–149). Evidences of silication are (1) pisolitic bauxitic clay or "chimney rock" present at the tops of deposits; it has formed from purer bauxite and grades downward into higher-grade bauxite, (2) veinlets of well-crystallized kaolinite cutting bauxite, and (3) deposits of low-grade bauxite in which the pisolites are empty or consist largely of kaolin. Silication probably was appreciably slowed down by an early cover of rather impermeable kaolin and silicated bauxite.

RESERVES

Estimates of reserves of bauxite, siliceous bauxite, bauxitic clay, and kaolin, as of 1960, are shown in table 1. All figures are conservative, especially those showing amounts of kaolin, but they indicate the order of magnitude of resources of different grades. The table was compiled by the author from reserve estimates for separate districts and from other data. For this compilation, bauxite was restricted to material which contains 15 percent or less of silica. No cutoff was put on iron content because it is commonly low. Siliceous bauxite is bauxitic material which contains more than 15 percent silica but which contains at least 24 percent of "available alumina." The "available alumina" is defined as the percent of alumina less 1.1 times the percent of silica and is based on the amount of alumina obtained from ore by the unmodified Bayer process. Bauxitic clay includes all other material in which the alumina content is greater than the silica content. The estimates of tonnage of kaolin include only material with less than 2 percent of sand.

TABLE 1.—*Estimated reserves of bauxite, bauxitic clay, and kaolin in bauxite districts of the Southeastern United States as of 1960*

[Results are in long tons except as indicated]

Bauxite: Not more than 15 percent SiO_2, in deposits and parts of deposits at least 5 feet thick.
Siliceous bauxite: More than 15 percent SiO_2, but at least 24 percent "available alumina" (defined as the percentage of Al_2O_3 less 1.1 times the percentage of SiO_2).
Bauxitic clay: More alumina than silica.
Kaolin: Less than 2 percent sand.

Locality	Bauxite						Siliceous bauxite	Bauxitic clay	Kaolin
	Average content (percent)		Measured	Indicated	Inferred	Total			
	SiO_2	Al_2O_3							
Coastal Plain:									
Georgia	12	56	300,000	130,000	170,000	600,000	600,000	6,500,000	150,000,000
Alabama	12	56	100,000	200,000	100,000	400,000	500,000	700,000	1,500,000
Mississippi	15	51		2,000	3,000	5,000	90,000	450,000	7,500,000
Appalachian region: Tennessee, Virginia, and parts of Alabama and Georgia	13	54	5,000	10,000	35,000	50,000	235,000	650,000	1,000,000
Total			405,000	342,000	308,000	1,055,000	1,425,000	8,300,000	160,000,000

Resources of siliceous bauxite and bauxitic clay are much greater than metallurgical-grade ore. Bauxite deposits in the region are characterized by a greater proportion of low-grade siliceous bauxite than of high-grade ore, and the tonnages of bauxitic clay and kaolin are even larger. Reserves of these low-grade materials are included in the table because of increased use in recent years. Much ore shipped during the 1950's averaged almost 20 percent silica and was a blend to obtain the highest possible recovery from a deposit. Bauxitic clay and the kaolin associated with bauxite are not usually mined, but they are a potential source of alumina that could be processed by such methods as the soda-lime-sinter process. In the future, these deposits may also become of interest to the clay industry. The greatest reserve of bauxitic clay and kaolin associated with bauxite is in the Andersonville and Irwinton districts, Georgia.

Probable reserves in the Southeastern States amount to a small fraction of total United States reserves of bauxite. If a figure of 70,700,000 long tons is taken as the amount of commercial bauxite in Arkansas (Gordon, Tracey, and Ellis, 1958, p. 168) and 1,055,000 long tons for the Southeastern States, total reserves for the country would amount to about 71,755,000 long tons. Reserves in the Southeastern States are, therefore, less than 1½ percent of the total for the country.

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