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GEOLOGICAL SURVEY BULLETIN 1199-L

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By JOHN C. DUNLAP, HARLAN R. BERGQUIST, LAWRENCE C. CRAIG, *and* ELIZABETH F. OVERSTREET

BAUXITE DEPOSITS OF THE SOUTHEASTERN UNITED STATES

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A description of the deposits in the Chattanooga, Indian Mound, and Elizabethton bauxite districts

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BAUXITE DEPOSITS OF TENNESSEE

By JOHN C. DUNLAP, HARLAN R. BERGQUIST
LAWRENCE C. CRAIG and ELIZABETH F. OVERSTREET

ABSTRACT

Bauxite deposits are known at 12 localities in the Chattanooga bauxite district in Hamilton County, Tenn., and 6 have been mined. There are 2 deposits in the Summit Knobs area, 7 on the east slope of Missionary Ridge, and 3 on the east slope of Big Ridge and Gold Point Ridge. All occur in areas underlain by dolomite of Late Cambrian age. All the deposits are less than 300 feet in greatest diameter; the maximum known thickness of bauxite and associated kaolin is 78 feet. The most common type of bauxite is soft and non-pisolitic; some is hard and pisolitic. Most of it is suitable only for chemical use or for metallurgical purposes other than extraction of aluminum. A total of 2.215 feet of exploratory drilling was done in 1942–43 in the Summit Knobs and Missionary Ridge areas.

A deposit of bauxite in Stewart County was mined and stockpiled during the 1930's. The deposit consists chiefly of sand and clay and in the upper part has a 300-foot-long lens of kaolin in which are thin lenses of bauxite. The area is underlain by gently dipping Warsaw Limestone (Mississippian) under a heavy cover of sand and gravel, some of which is probably a remnant of the Tuscaloosa Formation of Late Cretaceous age.

Two deposits of bauxite are known in the Elizabethton district, Carter County, about 200 miles northeast of the Chattanooga district in an area underlain by rocks ranging in age from Early Cambrian to Ordovician.

All the deposits in these three counties were probably deposited in sinkholes or solution channels.

INTRODUCTION

The bauxite deposits of Tennessee were studied in 1942 and 1943 by the U.S. Geological Survey and the U.S. Bureau of Mines as part of a nationwide strategic-minerals investigation undertaken by the Federal Government during World War II. The Tennessee Division of Geology also cooperated in the geologic work. In the State, bauxite is known in three widely separated districts, from east to west—the Elizabethton, Chattanooga, and Indian Mound. (See fig. 1.) The

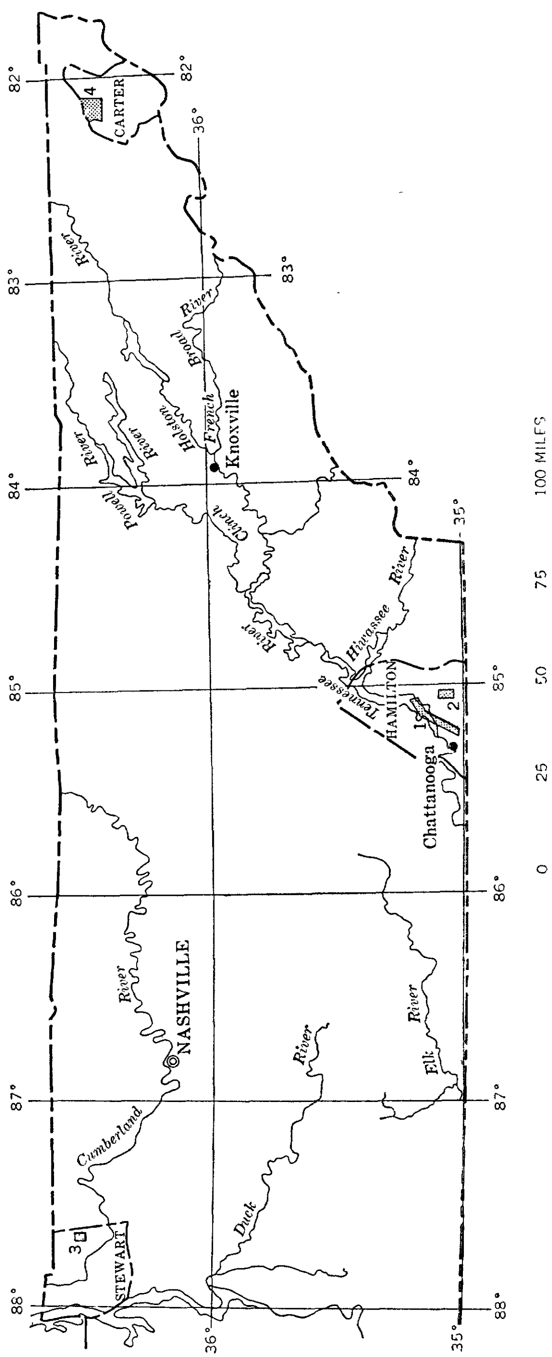

FIGURE 1.—Central and eastern Tennessee, showing location of bauxite districts. 1 and 2, Missionary Ridge and Summit Knobs areas of the Chattanooga district; 3, Indian Mound district; 4, Elizabethton district.

Elizabethton district was studied by L. C. Craig in 1942. J. C. Dunlap, assisted by R. L. Heller, J. S. Cullison, and R. E. Goodwin, studied the Chattanooga district and planned the drilling program in 1942–43. H. R. Bergquist investigated the deposits in the Indian Mound district in 1943. This report was compiled by E. F. Overstreet, who studied the mineralogy of the deposits.

The authors are indebted to the late F. K. McIntosh, project engineer, Bureau of Mines, for cooperation during the drilling program and to the late Josiah Bridge for identification of fossils. The Aluminum Co. of America and the General Abrasive Co., Inc., generously gave free access to files containing drill records and chemical analyses. Dr. J. D. Gaither and other property owners furnished much helpful information.

CHATTANOOGA BAUXITE DISTRICT

The Chattanooga bauxite district (fig. 1) is in the Appalachian Valley, in the southern part of Hamilton County. Unequal erosion of the folded and faulted sedimentary rocks underlying the Chattanooga district has resulted in roughly parallel ridges and valleys that generally trend northeast; maximum topographic relief is about 300 feet. The floors of the valleys are generally underlain by shale or by limestone or dolomite, both of which have a low chert content; the ridges are formed by very cherty carbonate rocks or sandstone.

The bauxite deposits and the sites recommended for exploration within the district are all within a few miles of paved roads. The district is served by five railroads: the Southern; the Cincinnati, New Orleans and Texas Pacific; the Central of Georgia; the Tennessee, Alabama and Georgia; and the Nashville, Chattanooga and St. Louis. The Tennessee River is navigable from its confluence with the Ohio River to a point more than a hundred miles upstream from Chattanooga.

Of the 12 deposits discovered in the district, 10 are in the Missionary Ridge area (pl. 1) and 2 are in the Summit Knobs area (pl. 1). Following reconnaissance geologic work by the Survey, the Bureau of Mines bored exploratory holes at three prospect sites from November 27, 1942, to March 13, 1943. Privately owned facilities, including a bucket-type rotary drill and a churn drill equipped with earth socket, were engaged by the Bureau for this work.

STRATIGRAPHY

CAMBRIAN

CONASAUGA SHALE

The Conasauga Shale, of Middle and Late Cambrian age, consists of green and purple shale and a thin section of limestone and dolomite at the top. Only the contact of the Conasauga Shale with the overlying Copper Ridge Dolomite (pl. 1) was mapped in this study.

COPPER RIDGE DOLOMITE (KNOX GROUP)

The Copper Ridge Dolomite, of Late Cambrian age, is deeply weathered in the Chattanooga district. The scattered exposures of undisintegrated rock indicate that the lower part of the formation is predominantly dark brownish-gray to nearly black crystalline dolomite that occurs in beds averaging about a foot in thickness. On freshly broken surfaces the dolomite emits a fetid odor. Light- to medium-gray dolomite is interbedded with the darker rock and is the predominant type in the upper half of the formation. Because of the scattered outcrops, the thickness of the Copper Ridge could not be measured accurately, but near Highway 11, in the Summit Knob area (pl. 1), the breadth of the Copper Ridge outcrop is about 3,800 feet and the dip, measured at the base of the formation, is 25°. From these figures the thickness of the Copper Ridge is calculated to be about 1,600 feet, which is intermediate between the thickness of 900 feet at the type section in Granger County, Tenn., and an estimated 2,000 feet in northern Alabama. A similar calculation gives 1,250 feet for the thickness of the Copper Ridge Dolomite above the Missionary Ridge fault on South Chickamauga Creek in the Missionary Ridge area.

The dolomite of the Copper Ridge is highly siliceous and on weathering yields a residuum of clay and large quantities of various types of chert of compact texture, most surfaces of which are rough and jagged though they appear to be fairly smooth when viewed from a distance. Differences in the types of chert serve as criteria for rough identification of the lower, middle, and upper parts of the Copper Ridge Dolomite. The lower part is characterized by chert fragments of several types, of which some are dark gray and contain structures resembling cryptozoans, whereas others are dark gray, oolitic, and friable; still other fragments include both dark-gray and light-gray spotted and banded varieties which, together with the dark oolitic chert just mentioned, are the most characteristic of all the types of chert in the Copper Ridge Dolomite. The middle part of the formation is represented by abundant fragments of oolitic chert in which the individual oolites are spherical and generally dark brown in a light-gray or bluish-gray matrix. The upper part is characterized by chert of various colors in massive beds at least 4 feet thick. Exposed surfaces of much of the chert in this part of the formation are light gray or bluish gray and have large darker gray blotches. Also present in abundance is tan chert containing great numbers of tiny white oolites, subspherical to elliptical in cross section, that are visible through a pocket lens. A third common type is brownish-gray to brown chert that contains dark-brown oolites. The sinistrally coiled gastropod, *Scaevogyra* cf. *S. swezeyi*, is present in fragments of residual chert that apparently represent a stratigraphic horizon that is approximately 600 feet below the top of the formation in the Missionary Ridge area and about 400 feet below the top in the Summit Knobs area. This index fossil is present also in the western part of the Appalachian Valley of Tennessee in widely distributed outcrops of similar dark odoriferous strata that are characteristic of the Copper Ridge Dolomite.

ORDOVICIAN

CHEPULTEPEC DOLOMITE (KNOX GROUP)

The Chepultepec Dolomite of Early Ordovician age consists predominantly of light- to dark-gray fine- to medium-grained cherty dolomite exposed in beds ½–2 feet thick in the Chattanooga district. The total thickness of the formation is approximately 670 feet as measured in scattered exposures along the north bank of South Chickamauga Creek opposite McCarty Station (pl. 1). In the Missionary Ridge area the base of the Chepultepec is marked by a bed of sandstone that is nowhere more than 6 inches thick. In some places this bed is quartzitic; in others it is composed of grains of quartz in a matrix of white chert. In its lower part it includes rounded chert pebbles and ellipsoidal voids that have resulted from removal of pebbles of soft or soluble materials. Nowhere in the Summit Knobs area is this sandstone bed more than 2 inches thick, and in most places it is absent. Where the stratum is not present, the base of the Chepultepec is arbitrarily drawn at the lowest occurrence of mealy fossiliferous chert pitted by cavities lined with quartz crystals. The top of the formation, which is not mapped on plate 1, can be defined as its contact with an overlying sequence of beds represented by dense nearly white residual chert containing fossils of the genus *Lecanospira*.

Much of the chert in the Chepultepec Dolomite is dense light-gray and blue-gray banded rock and in the upper part of the formation occurs as thin, lenticular beds and flattened nodules. Closely spaced thin laminae of chert or silty material protrude from weathered surfaces that intersect bedding planes at many horizons throughout the formation. Also protruding from some surfaces are masses of a mealy type of chert in which are many cavities, or geodes, lined with quartz crystals. Dolomite containing pitted chert of this type is abundant and is characteristic of the Chepultepec of the Chattanooga district. The pitted chert also commonly contains fossils, among which are *Helicotoma uniangulata* (one of the Chepultepec index fossils) as well as gastropods belonging to the genera *Euomphalopsis*, *Gasconadia*, and *Schizopea*.

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CHICKAMAUGA LIMESTONE

The Chickamauga Limestone of Middle and Late Ordovician age is in contact with the Copper Ridge Dolomite along the trace of the Missionary Ridge thrust fault and underlies that formation in the subsurface of the area occupied by the overriding block, west of the contact. As exposed near the fault, the Chickamauga consists largely of thin-bedded limestone strata and contains some persistent beds of bentonite; it is thus readily distinguishable from the dolomite units of the Knox Group. The extent of the Chickamauga and its lithologic units in the Chattanooga district and elsewhere in east Tennessee have been discussed by Rodgers (1953).

STRUCTURE

In all except two exposures in this district for which data on the Copper Ridge Dolomite and the Chepultepec Dolomite are available, these formations dip 10°–25° SE. In an exposure opposite the fertilizer plant at McCarty Station (pl. 1), an anomalous southwest dip of the upper beds of the Chepultepec Dolomite shows some evidence of shearing. About 4 miles farther southwest, at a point between Mount Olivet cemetary and the Bachman tubes, obscure folding or minor faulting is suggested by erratic distribution of the basal sandstone of the Chepultepec.

A notable geologic feature of the Missionary Ridge area is the Missionary Ridge fault, a low-angle reverse fault in which the lower part of the Copper Ridge Dolomite (Upper Cambrian) has moved northwestward to a position overlying the Chickamauga Limestone (Middle and Upper Ordovician). Adjacent to a gap in Missionary Ridge at Rossville, Ga., just beyond the south limit of the area mapped, the trace of this fault is about halfway up the northwest side of the ridge. The trace occupies progressively higher positions northeastward to a point just south of the Wilcox tunnel, in Chattanooga, where it is on the northwest slope, close to the top of the ridge. Between that point and the northeast end of Gold Point Ridge, which is the extreme northeastern continuation of Missionary Ridge, the trace extends along the uppermost part of the northwest slope in all except two localities. In one of these, in the vicinity of Gold Point Circle Road, the trace forms a reentrant and crosses over to the southeast side of the ridge for a distance of approximately half a mile. In the other locality, half a mile northeast of Burks Chapel, it again occupies a position on the southeast slope of the ridge. As shown on the map (pl. 1) the trace here forms a second reentrant within which occur two klippen: one on a spur that projects southeastward and another on top of the ridge. The interpretation indicated on the map is based solely on the abundance of chert fragments in the areas shown as klippen, as contrasted with the small amount of chert debris on the surfaces surrounding these areas. According to an alternative interpretation the outcrop of the Copper Ridge Dolomite would be assumed to extend uninterruptedly along the part of the ridgetop on which the postulated upper klippe is shown on the map. The trace would accordingly define a fenster, rather than a reentrant, and the lower klippe would be represented on the map as occurring within this postulated fenster. In either interpretation the scattered chert fragments on the surface surrounding the upper klippe can be assumed to represent residual debris resulting from disintegration of the Copper Ridge Dolomite. In the interpretation shown on the map this debris is supposed to have slid down from positions above the fault plane, whereas in the alternative hypothesis the chert fragments are regarded as virtually in their original position.

The plane of the thrust fault is well exposed at two places in the east Chattanooga quadrangle. An excellent exposure occurs 400 feet north of the north end of the bridge over South Chickamauga Creek, at the edge of the road leading to King's Point Cemetery. Here the fault resembles a bedding surface, but the dolomite of the overthrust block is shattered and crushed. At points where its attitude is unmistakable, the plane strikes N. 20° E. and dips 21° SE.; on the northwest (updip) side of the exposure, however, where the attitude is less obvious, the fault plane appears to dip somewhat less steeply. In a second exposure, on the north shore of Chickamauga Lake, 3,300 feet upstream from the dam, the strike of the fault plane is N. 40° E.; its dip is 10° SE. in the updip part of the exposure, but steepens to 17° in the downdip part. For a horizontal distance of about 125 feet east of the plane of the thrust fault, the dolomite of the overthrust block has been mylonitized, so that a polished section of a specimen shows innumerable unoriented fractures that obscure the bedding planes and other structural features. Weathered surfaces of this mylonitized dolomite have a pseudopebbly appearance.

A zone of accessory faulting within the overthrust block is suggested by cores from diamond-drill holes bored by the Tennessee Valley Authority near the boat harbor on the south shore of Chickamauga Lake and also farther southwest in the large water-filled sink that lies halfway between the boat harbor and South Chickamauga Creek. This zone of deformation, which was recognized by McGavock (1941, p. 226), was probably caused by forces that were involved in the movement on the Missionary Ridge thrust fault, the trace of which parallels the zone. The zone probably continues northeastward beyond the Tennessee River and southwestward under the narrow valley that crosses South Chickamauga Creek just east of the trace of the Missionary Ridge fault.

BAUXITE DEPOSITS

DISCOVERY AND EXPLOITATION

Whitlatch (1939, p. 3) reported that bauxite was first discovered in the Chattanooga district in 1906, when the McCallie tunnel was driven through Missionary Ridge. The authors of the present report, however, were informed that the first discovery was made in 1904, when a well was dug at what later became the Isabella Stewart mine. Bauxite is now known to occur at 12 places in the district; ore has been mined and shipped from six of these, but none has been mined since the 1920's. Most of the ore came from the Isabella Stewart, or Perry mine, which is reported to have yielded about 300,000 long tons; it is probable, however, that the actual tonnage shipped from this mine was somewhat less.

CHARACTER OF THE ORE

The classification of bauxite used in this report is mainly that suggested by Thoenen and Burchard (1941, p. 38). Grade D of that classification, however, is divided by us into two parts which are designated D and D′. Grade D, as redefined, includes materials conforming to Thoenen and Burchard's grade D that contain more alumina than silica and some gibbsite. Grade D′ is defined as material classifiable as kaolin, which contains more silica than alumina and is composed largely of the mineral kaolinite. The modified classification is given in table 1.

TABLE 1. *Modified Thoenen-Burchard classification of bauxite (and kaolin)*

Grade	Alumina (percent)	Silica (percent)
A	+55	Less than 7.
B	50–55	Less than 15.
C	45–50	Less than 30.
D	30–45	Less than alumina.
D′ (kaolin)	More than 30	More than alumina.

In this district the bauxite is mostly soft and nonpisolitic. Distributed through the material of this kind, however, are dornicks of hard pisolitic bauxite, as well as many isolated individual pisolites that have probably broken away from such bodies. Of the two types of material thus recognized, the pisolitic material is the more valuable as ore, but it constitutes only a small proportion of the total bauxite in the deposits. Both the nonpisolitic and the pisolitic materials range in color from white or cream to dark red, depending on differences in the percentages of contained iron. Compared with bauxite from Arkansas, that from the Chattanooga district is generally higher in silica but lower in iron and titania. An analysis typical of bauxite from this district shows about 50 percent alumina, 21 percent silica, 2.5 percent iron oxide, 2.5 percent titania, and 24 percent ignition loss. Although the iron content is commonly low, that of parts of some deposits reaches 15 or even 20 percent. The iron content is generally highest at the periphery of a deposit and decreases toward its center—a relation that is well exemplified by the J. F. Smith deposit. Some of the hard pisolitic bauxite contains as much as 62 percent alumina and as little as 3 percent silica and 1.5 percent iron. The bauxite in most of the deposits is, nevertheless, low-grade material that is useful only for chemical or other nonmetallurgical purposes.

TOPOGRAPHIC POSITION

All the bauxite deposits in the Missionary Ridge are at the inner edge of a topographic bench on the southeast slope of Missionary Ridge and of its continuation (Big Ridge and Gold Point Ridge) north of the Tennessee River, and all are between 840 and 920 feet above sea level. The bench is well preserved from the Isabella Stewart mine to the south limit of the area, but it has been largely destroyed by erosion north of the Tennessee River. The two known bauxite deposits in the Summit Knobs area are near the crest of Summit Knobs Ridge, and both are at an altitude of about 950 feet above sea level.

SHAPE AND SIZE OF DEPOSITS

Inasmuch as the bauxite deposits of the Appalachian region seem clearly to be sinkhole fillings, their shapes probably closely resemble those of modern sinks. In the Chattanooga district the deposits that have been developed or explored sufficiently to disclose shape are elliptical or subcircular in plan and are less than 300 feet in maximum horizontal dimension; the greatest known depth from the surface to the bottom of a deposit is 190 feet. The maximum thickness of the overburden, which consists of clay and chert fragments, is approximately 40 feet.

ORIGIN

The theory that Appalachian bauxite and kaolin deposits were deposited in sinkholes is supported by information obtained by drilling in the Chattanooga district. Subsurface data presented by McGavock (1941, p. 226) demonstrate that broken rock of the Copper Ridge Dolomite occurs in association with a modern sinkhole in the fractured and faulted zone east of the trace of the Missionary Ridge fault in the vicinity of the Chickamauga dam. The topographic configuration of the sloping ground on the east side of the ridge suggests, moreover, that the zone of shattered rock continues for some distance parallel to that fault. All the bauxite deposits in the Missionary Ridge area are alined along or near the inferred outcrop of this zone, and this coincidence suggests that the fracturing may have played a major role in their origin. After the deformational movements that caused the shattering had ceased, circulation of underground water presumably was more active in the vicinity of this zone than elsewhere in the subsurface of the belt where the Copper Ridge Dolomite crops out. The soluble constituents of the dolomite may therefore have dissolved away along this zone so rapidly as to promote formation of numerous sinkholes; in some of these, materials may have accumulated that subsequently became altered chemically to form the present deposits of bauxite. Admittedly, however, the alinement of the bauxite deposits can be satisfactorily explained without invoking the rather tenuous hypothesis of a continuous zone of fracturing parallel to the Missionary Ridge fault trace. Two alternative hypotheses that seem to deserve consideration are:

1. Formation of bauxite deposits in sinks along the outcrop of a bed, or sequence of beds, in which the porosity, the content of soluble matter, or both may have been greater than average for the Copper Ridge Dolomite.
2. Formation of bauxite as a result of extensive development of karst topography on an ancient intermontane plain, which has been destroyed by erosion except for a small part now represented by the topographic bench that extends intermittently along the southeast slope of Missionary Ridge. Under this interpretation, the idea that the bench is an expression of bedrock structure would, of course, be abandoned.

The true explanation of the alinement may involve a combination of several hypotheses including, or comparable to, those suggested in the foregoing discussion.

The bauxite is thought to be a product of chemical weathering whereby silicates of alumina—such as kaolinite, feldspars, and micas—have lost their content of silica. In the authors' opinion, however, the parent material was not the chert-bearing residual clay that surrounds the deposits but was more probably transported debris. This view is based primarily on the following observations:

1. The contact of the residual clay with the materials of the ore bodies is sharp, whereas a transitional contact would be expected if the deposits were merely an altered phase of the enclosing material.
2. The bauxite and the associated kaolin are mixed with chert-free clay and quartz sand, materials that have not been found in association with the residuum of the Copper Ridge Dolomite in the Missionary Ridge area.

AGE

Information relating to the age of the bauxite deposits of the Chattanooga district suggests that their geologic history differs little, if any, from that of deposits elsewhere in the Appalachian region. The deposits probably formed in sinkholes that developed after completion of the most intensive phases of post-Paleozoic deformation and denudation in the region, in the course of long-continued leaching which removed the soluble constituents of a sufficiently large volume of Copper Ridge Dolomite to account for the extensive accumulations of residual material that occur along its outcrop. Evidence summarized by Warren and others (1965) suggests that the bauxitization took place in early Tertiary (probably Eocene) time. Some lignitic clay was taken from the Isabella Stewart mine while it was in operation, but fossil plant remains in fragments of such material that have been found on the mine dumps are not sufficiently well preserved for identification. Further evidence of the age of the bauxite deposits is desirable, and any fossil plant remains that may be discovered in the course of further mining in this district should therefore be submitted to a paleobotanist for identification.

MINES AND PROSPECTS

MISSIONARY RIDGE AREA

ISABELLA STEWART (PERRY) MINE

The bauxite deposit at the Isabella Stewart mine near East Chattanooga occurs at an altitude of 870 feet at the northwest (inner) edge of the topographic bench that extends along the southeast slope of Missionary Ridge (pl. 1). This mine is the largest in the Chattanooga district, and if it actually produced the 300,000 tons of bauxite generally credited to it (Whitlatch, 1939, p. 6), the bauxite deposit from which this tonnage was taken was the largest that has been discovered in the Appalachian Valley. Total production, however, has been variously reported, and Mr. C. D. McCollister, manager of the American Cyanamid and Chemical Co. plant in Chattanooga, informed us that about 175,000 to 200,000 tons of good ore was mined. In view of the total recorded bauxite production from the State, as determined from annual statistics gathered by the U.S. Geological Survey, the reported 300,000 tons seems to be much too high; it may represent material moved in mining rather than that shipped, or it may include material classed and sold as clay.

The deposit was discovered during the digging of a well (Ashley, 1911, p. 212), according to Mr. McCollister, in 1904; if so, it was the first discovery of bauxite in the State. The mine was opened by the National Bauxite Co. in 1907 and was operated by that company until 1916. It was later bought by the Kalbfleisch Chemical Co. (now

American Cyanamid and Chemical Co.) by whom it was operated until about 1924.

The mine, as observed in 1913, was described by Phalen (1914, p. 4) as follows:

Formerly there were two mines or pits near this place, situated within 250 yards of each other on a northeast-southwest line. The northeast pit, known as the Perry mine, was in operation during 1913; the other was filled with water and has not been worked for several years. From a small hole in the ground the Perry mine has been constantly enlarged until it is now 125 to 150 feet in depth. Its diameter at the surface is approximately 250 to 300 feet. Test pits have been sunk 20 to 25 feet below the bottom, and good ore has been found at this depth, with no means of telling how much farther downward it may extend. The tonnage of bauxite ore removed from this one mine runs up into the thousands. The Perry mine, in fact, has grown so large that among the plans for the future is one for the installation of a steam shovel, a novelty in a southern Appalachian bauxite mine.

The dimensions of the pit at the water level in 1944 were about 200 by 125 feet, but these must be somewhat larger than the dimensions of the ore body, as considerable stripping is reported to have been done around the edges of the bauxite. The maximum extent of the pit at the original ground surface is uncertain because its outline is obscured by dumps and erosion. The deposit was described by Ashley (1911, p. 212) as "egg-shaped," and he stated that the horizontal limits of the ore first increased with depth, then diminished. Large masses of clay, or clay "horses," extended into the deposit from the periphery or occurred within the deposit as pillars. One clay "horse" or pillar which extended to the bottom of the mine was never removed and still projects above the water near the west end of the mine.

Most of the bauxite was nonpisolitic or earthy and was gray, cream, or red. Irregular masses or dornicks of red and gray hard pisolitic bauxite were scattered through the soft nonpisolitic bauxite. Chemical analyses of ore shipped in the early 1920's showed 53–57 percent alumina, 13–23 percent silica, and less than 1 percent iron oxide. The bauxite was described in considerable detail by Phalen (1914, p. 4, 5), who reported the following analyses, in percent, of six carload lots:

Analyses of bauxite from Missionary Ridge area, Tennessee

	1	2	3	4	5	6
Insoluble	12.13	11.15	11.33	11.07	13.12	12.65
Loss on ignition	28.97	30.04	30.20	30.00	30.39	30.31
Alumina (Al_2O_3)	57.56	57.63	57.37	57.83	55.11	55.50
Iron oxide (Fe_2O_3)	1.34	1.18	1.10	1.10	1.38	1.34

Above the water level, the residual clay and chert enclosing the ore body are exposed on all sides. The mine would have to be unwatered to determine the amount of ore that remains in the lower parts of the deposit.

BRANNAN-MONTAGUE MINE

The opencuts and prospect pits of the Brannan-Montague bauxite mine are half a mile southwest of the Isabella Stewart mine and about 1,700 feet northeast of the east portal of the Wilcox tunnel (pl. 1), at an altitude of 850 feet.

The mine workings consist of two main cuts, a third cut between these two, and several prospect pits (fig. 2). Cut 1 has been called the Brannan mine and cut 2, the Montague mine, but both are probably in the same ore body.

Bauxite float at the surface is reported by local residents to have led to the discovery of this deposit. It was mined intermittently between 1920 and 1926. Old records indicate that 3,248 tons of ore was shipped from the two cuts.

The bauxite—shown by pattern (fig. 2) in cuts 1 and 2, on the dump beside pit 1, and in small amount in the southeast wall of cut 3—occurs on the periphery of a mass of variegated sandy and silty clay that is exposed in the southwest wall of cut 1, in the bottom and on the west side of cut 3, and in pit 2. This variegated sandy and silty clay is similar to that in the center of the Smith ore body in the Summit Knobs area, and the relation of the variegated clay to the bauxite is the same as that between clay and bauxite at the surface at the Smith deposit. The deposit seems to be elliptical in outline with the greatest diameter, about 250 feet, in a northwest direction, but no bauxite has been found in the central part of the area so outlined.

Nonpisolitic and pisolitic bauxite are present, but the pisolitic type seems to be more abundant than it is in some of the other deposits in the district. Following are the results, in percent, of analyses by the Tennessee Division of Geology (Whitlatch, 1939, p. 7) of samples from the Montague cut:

Analyses of selected samples, Montague mine

[n.d., not determined]

Sample	Alumina	Silica or insoluble	Iron oxides	Titania	Water	Total
Hard ore	63.65	4.67	3.59	n.d.	n.d.	--------
Soft ore	51.73	27.68	2.79	n.d.	n.d.	--------
Upper end	55.75	22.27	1.87	0.80	19.12	99.81
Oolitic white	51.39	19.74	1.43	.82	26.80	100.18
About 1½ feet from top	52.15	22.48	1.53	.81	22.92	99.89
Opening extending from Brannan property into Montague property	52.97	19.86	1.57	------	(1)	74.40

1 Dried sample.

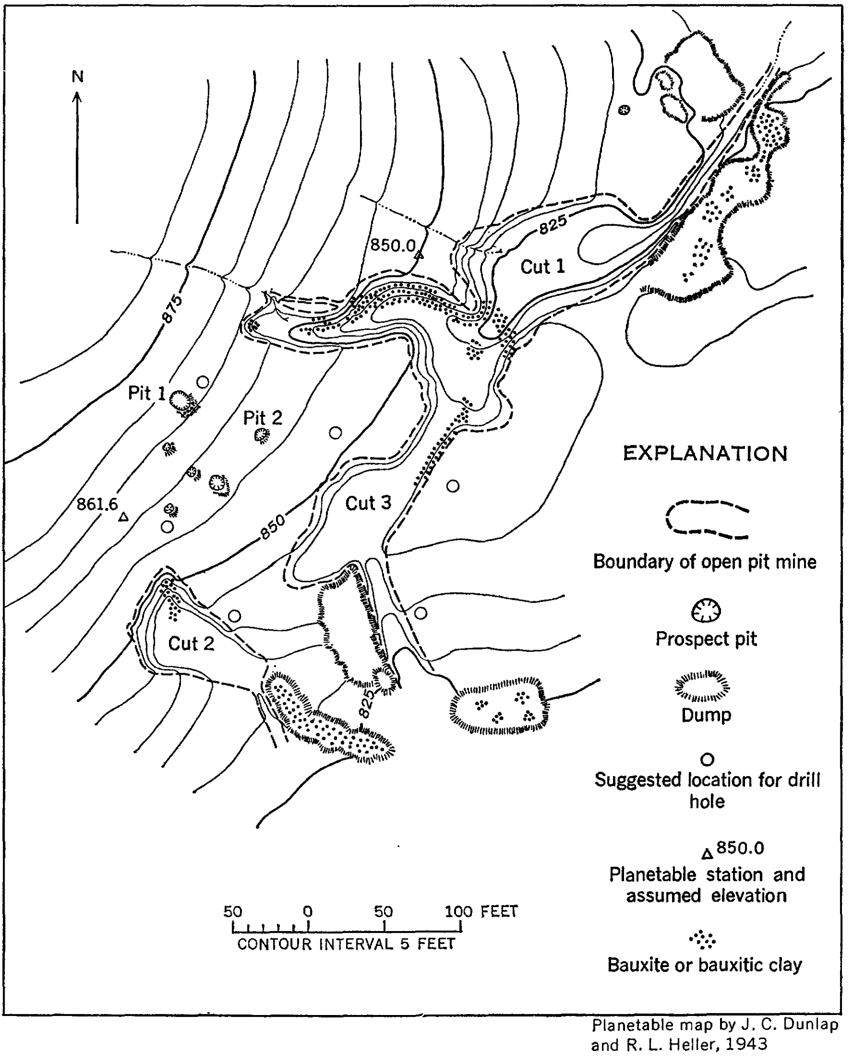

FIGURE 2.—Brannan-Montague bauxite mine, Missionary Ridge area, Chattanooga district, Tennessee.

If this deposit is prospected further, five holes whose locations are shown on figure 2 should be drilled to investigate the possibility that bauxite entirely surrounds the sandy clay and extends beneath it. Holes at the recommended locations should be drilled through bauxite and sandy clay into the underlying residual clays containing fragments of chert.

WILCOX (BUCHOLZ ESTATE) PROSPECT

The Wilcox prospect is on the east slope of Missionary Ridge approximately 1,600 feet south and slightly west of the east portal of the Wilcox tunnel and 400 feet southeast of the east city limits of Chattanooga (pl. 1). It is approximately 300 feet northeast of the center of a pronounced valley that cuts into the east slope of Missionary Ridge. The altitude is 910 feet.

Prior to the exploration by the Bureau of Mines and the Geological Survey, one large and three smaller test pits had been dug at this prospect (pl. 2). Bauxite is exposed in all walls of the large pit, but there is none in the 14-foot-deep pit east of the large pit. The other two small pits are very shallow and are partly filled with overburden and bauxite taken from the large pit; therefore, it is not clear whether or not bauxite was penetrated. No mining has been done at this property.

Nine holes, whose locations are shown in plate 2, were drilled in the Geological Survey-Bureau of Mines joint project. The highest grade bauxite material was obtained from hole 33. Chemical analyses of the drill core from this hole were reported in table 2 by McIntosh (1949, p. 29). The part of the hole below the material analyzed, from 73 to 85 feet in depth, was drilled in residual sandy clay and sand containing some chert.

TABLE 2.—*Chemical analyses of cores from drill hole 33, Wilcox prospect*

Depth (feet)		Analyses (percent)				
From	To	Al_2O_3	SiO_2	Fe_2O_3	TiO_2	Ignition loss
4	9	37. 1	36. 6	5. 68	2. 05	17. 3
9	14	44. 2	31. 2	1. 90	2. 58	19. 0
14	19	37. 9	44. 4	1. 00	1. 93	14. 0
19	24	37. 4	44. 2	1. 33	2. 39	13. 6
24	29	37. 2	44. 5	1. 13	2. 16	13. 8
29	34	35. 5	43. 9	2. 34	1. 88	13. 6
34	39	35. 3	43. 1	5. 98	1. 33	13. 0
39	44	35. 3	41. 8	6. 09	1. 57	13. 1
44	49	40. 0	41. 5	1. 25	2. 19	15. 1
49	54	48. 1	23. 2	3. 20	2. 26	22. 4
54	59	50. 3	23. 1	3. 49	1. 79	22. 3
59	64	50. 9	19. 9	2. 08	2. 53	24. 0
64	69	50. 2	23. 4	1. 25	1. 87	22. 8
69	73	46. 6	29. 7	1. 80	2. 00	20. 1

Bauxitic clay occurs near the top and near the bottom of the hole. At the top of the deposit, at a depth of 9–14 feet, it is mixed with clay and contains few pisolites. From 14 to 47½ feet the hole penetrated plastic clay, generally white to cream colored in the upper part and red in the lower. Between 47½ and 70 feet the hole was in fragmental nonpisolitic bauxite together with pebble-sized pieces of pisolitic bauxite and some admixed plastic clay. Chemical analyses show the material in this interval to be bauxite of grade C on the basis of a rather high silica content, although the alumina content is a fraction of a percent higher than the minimum alumina requirement of 50 percent for that grade. The limits of the 5-foot intervals sampled for chemical analysis do not exactly coincide with the contacts between lithologically different materials. As a result, the lowest sample analyzed is a mixture of the bauxite above 70 feet and the sandy clay below that depth, and the sample of the top of the bauxite (from 44 to 49 feet) is a mixture of clay above 47½ feet and the bauxite of grade C below 47½ feet.

The deposit extends southeastward to hole 34 and northward to hole 30, but only kaolin was penetrated in these holes. The kaolin in hole 34 is compact and massive, generally dark red streaked with white or, rarely, green. It is overlain and underlain by dark red sandy clay and chert. Chemical analyses (McIntosh, 1949, p. 30) of the kaolin in hole 34 are as follows:

Depth (feet)		Analyses (percent)				
From	To	Al_2O_3	SiO_2	Fe_2O_3	TiO_2	Ignition loss
15	20	30. 4	50. 1	3. 53	2. 15	12. 1
20	25	37. 2	43. 6	3. 37	2. 05	13. 4
25	30	32. 5	40. 0	11. 50	1. 79	12. 2
30	35	31. 9	42. 9	9. 93	1. 16	11. 9
35	40	26. 5	45. 8	14. 00	. 87	11. 4
40	45	25. 0	52. 1	10. 30	. 99	9. 7

In hole 30, the material between depths of 12 and 18 feet was plastic slightly gritty clay. The clay was not analyzed but is similar in appearance to clays whose known chemical composition conforms to that of grade D′. In hole 37, about 45 feet northwest of hole 33, at a depth of 6–7 feet the drill penetrated a mixture of sandy clay containing some pisolitic material interbedded with a few feet of sandy chert-free clay. This mixture was not analyzed as it was considered too sandy to be a part of the deposit through which hole 33 was drilled. In all other holes the only material found was sandy clay containing abundant fragments of residual chert and some chert breccia cemented with limonite.

A selected sample of pisolitic bauxite from the large pit is material of grade C, and an incomplete analysis of a channel sample from the wall of the pit also indicated material of that grade.

Isopachs drawn on the basis of data from drill holes and test pits indicate that the Wilcox prospect encompasses a small body of bauxite and kaolin, roughly cone-shaped in cross section and elongate north to south in plan (pl. 2). The body is about 80 feet long and 40 feet wide, and its maximum depth is 70 feet. The approximate limits of materials of grades C, D, and D′ are shown in the sections on plate 2, but because the data are incomplete, it is not feasible to draw isopachs corresponding to each grade. The isopachs represent the total thickness of bauxite plus kaolin.

On the basis of data on the analyzed samples the probable percentage of each grade of material in the Wilcox prospect has been calculated as follows:

Grade	*Percent*	*Grade*	*Percent*
A	0	D	12
B	0	D′	59
C	29		

The weighted average of all the analyses of kaolin and bauxite is as follows:

	Percent		*Percent*
Al_2O_3	39.98	Ignition loss	16.34
Insoluble	36.84		
Fe_2O_3	3.77	Total	98.97
TiO_2	2.04		

It was hoped that the areal extent of the bauxite would be so large that bauxite would be found at relatively widely spaced locations. Drilling was discontinued when sufficient holes had been drilled to show that the deposit had a very small areal extent and thickness. Additional holes, if drilled at three locations indicated on plate 2, would provide data whereby isopachs of greater accuracy than those shown could be drawn.

HORNVILLE MINE

The Hornville mine is at the east edge of the Chattanooga 7½-minute quadrangle, approximately half a mile south of the Wilcox prospect and 2,000 feet northeast of the intersection of Shallowford and Crest Roads on the top of Missionary Ridge (pl. 1). The name Hornville has been adopted for this mine because of its proximity to a crossroads of that name. The mine is on the northeast side and part of the bottom of a shallow valley at an altitude of 850 feet. Though the previously mentioned topographic bench has been eroded here, the mine is at the altitude at which the projection of the bench intersects the east slope of Missionary Ridge.

In 1943 the workings consisted of one pit about 30 feet in diameter and about 15 feet deep. Only residual clay and chert are exposed in the walls, and no bauxite is exposed in the bottom of the pit. The entire ore body seems to have been mined out, but the amount extracted is not known. Float of pisolitic material is reported by local residents to have led to the discovery of the deposit, which was worked by Mr. Perry who operated the Isabella Stewart mine for a time.

Coarsely pisolitic cream-colored, pink, and dark-red bauxite is present on a small dump beside the pit. No analysis of this material is available. The shape of the pit indicates that the ore body was nearly circular and not more than 30 feet in diameter. As the pit has caved, its original floor is concealed, but its maximum depth seems to have been no more than 25 feet. As the ore body has apparently been completely mined out, no additional prospecting is recommended.

McCALLIE TUNNEL PROSPECT

About 3 to 5 tons of bauxite was found in 1906 in a small mass of gray clay that was exposed along the south wall of the entrance of the east end of the McCallie Avenue tunnel, 415 feet southeast of the Hornville mine (pl. 1). An analysis of a specimen of this bauxite by the Kalbfleisch Co. gave the following results in percent:

Alumina	54.79	Iron oxide	1.96
Insoluble	21.35	Ignition loss	23.25

The small mass of gray clay does not seem to extend in any direction. This bauxite deposit is reported by Whitlatch (1939, p. 3) to have been the first discovered in the Chattanooga district.

BENNETT MINE

The Bennett mine is 600 feet from the south edge of the Chattanooga quadrangle (pl. 1). The mine is in the bottom of a broad, shallow valley on the east side of Missionary Ridge at an altitude of 850 feet. One small and one large pit have been dug in the deposit; both pits were about 6 feet deep in 1944. In records of the Bucholz estate, owner of the property, 800–1,000 tons of bauxite is reported to have been produced. The ore body seems to have been elliptical in outline, measuring about 75 feet by 50 feet horizontally, and was at least 6 feet deep. Bauxitic clay and hard pisolitic bauxite occur in the northwest wall and, in small amounts, near the bottom of the south wall. Most of the bauxite is pink to buff and contains medium-sized to large pisolites, but there is some soft nonpisolitic bauxite. No analyses are available, but the bauxite is estimated to be of approximately the same grade as other deposits in the Chattanooga district. The Bennett was not a large deposit, but it may extend a short distance to the northwest and to the south and to a greater depth. A possible lateral extension in depth should be tested by a hole near the northeast edge of the larger pit. Although the maximum observed thickness of overburden is about 5 feet, in places it may be much greater, and test holes should therefore be drilled to a depth of at least 20 feet.

BENNETT PROSPECT

The Bennett prospect is just north of the south edge of the Chattanooga quadrangle, about 400 feet south of the Bennett mine (pl. 1). It is on the northeast side of a small gully at an altitude of 925 feet. No mining has been done here, but dornicks of hard pisolitic bauxite are exposed in a few shallow pits in an area about 50 feet square. Nonpisolitic bauxite is probably also present but was not seen. No chemical analyses are available. The size and shape of the body in which the exposed material occurs is unknown.

This prospect seems to be one of the most promising in the Missionary Ridge area. Favorable features are the considerable amount of pisolitic bauxite exposed in the pits and the rather high altitude. If exploratory drilling is ever done here, the first hole should be located near the center of the area covered by the pits, and, unless the bauxite is found to extend deeper than 50 feet, additional holes should not be spaced more than 25 feet apart.

SUMMIT KNOBS AREA

Only two bauxite deposits, the J. F. Smith and Willie Moore prospects, are known in the Summit Knobs area; both of these are in the lower part of the Copper Ridge Dolomite, which is in normal contact with the underlying Conasauga Shale. The Smith deposit, according to computations based on the dip of the beds and breadth of outcrop, is about 450 feet stratigraphically above the base of the Copper Ridge, and the Moore deposit seems to be in about the same stratigraphic position.

WILLIE MOORE PROSPECT

The Willie Moore prospect is in the southwest part of the west-central part of the Ooltewah 7½-minute quadrangle, approximately 2 miles south-southwest of Summit, Hamilton County (pl. 1). It occupies a concavity in the hillside at the south end of a ridge, at an altitude of 954 feet.

A few tons of hard pisolitic bauxite were taken from a pit 75 feet long and 45 feet wide. Three shallow test pits were sunk on the hillside above the large pit. The test pit northeast of the main pit (fig. 3) showed white and pink bauxitic clay, but the pits to the north and northwest were barren. The size of trees in the main pit and the

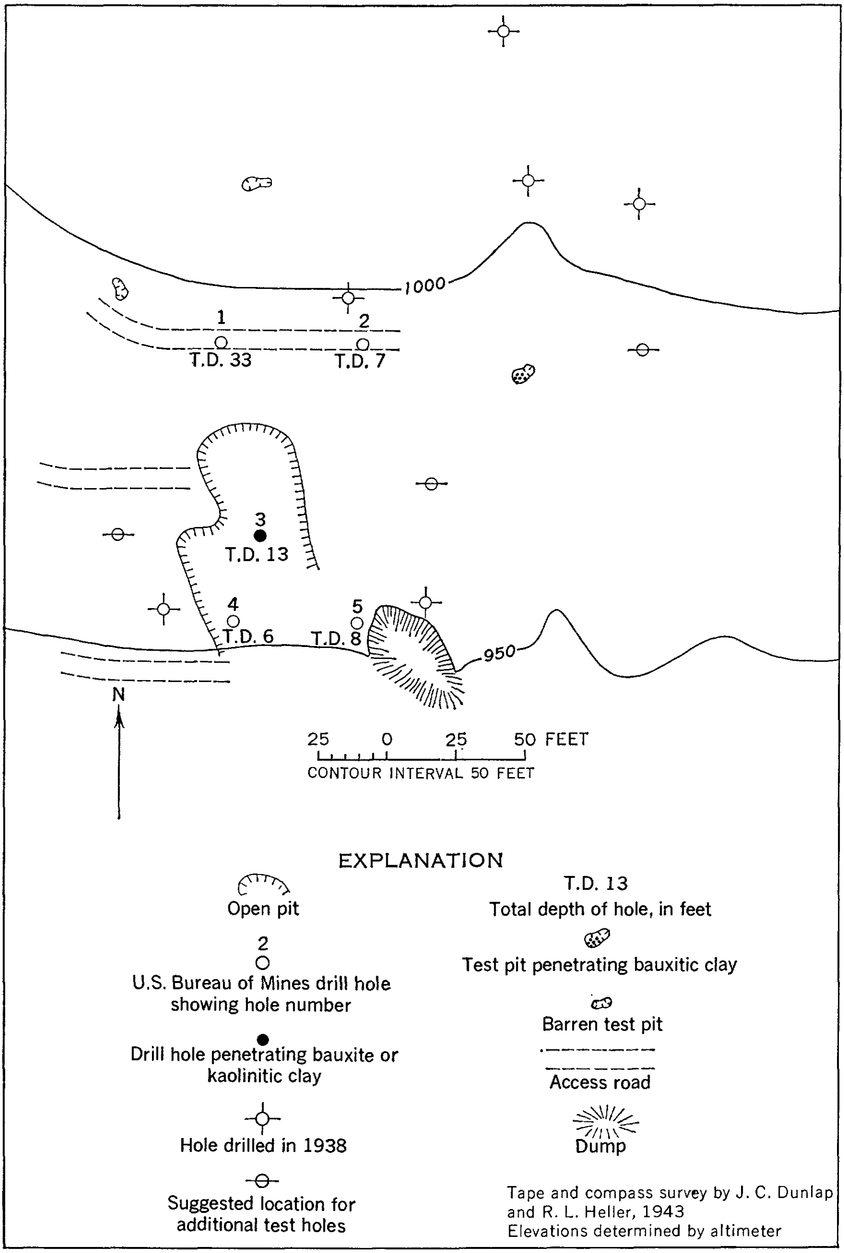

FIGURE 3.—Willie Moore prospect, Summit Knobs area, Chattanooga district, Tennessee.

slumped condition of all pits indicate that they were probably dug about 20 years prior to the time of our investigation. Eight holes were drilled in 1938, but neither the results nor the identity of the people who drilled them could be learned.

Five holes were drilled during the Bureau of Mines-Geological Survey joint project (fig. 3). The highest-grade material discovered was in hole 3 which penetrated 9 feet 10 inches of chert-free kaolinitic clay, of which the upper 5 feet contained 33.1 percent alumina and 43.7 percent insolubles (grade D′); the lower 4 feet was clay containing 29.1 percent alumina and 47.7 percent silica. The remaining holes, in which only sandy clay containing abundant grain- to boulder-sized chert fragments was found, were abandoned at shallow depths because of the great difficulty of penetrating this material with the bucket drill. When drilling was discontinued, because of the unsatisfactory performance of the drill and the difficulty in moving equipment during rainy weather, all possible extensions of the ore body had not been investigated.

This body of bauxite seems to be an erosional remnant of a deposit that originally extended farther to the south. The concavity in the hillside on which it occurs suggests that the bauxite and bauxitic clay may occur as a veneer on the north wall of a partially eroded sink whose postulated north limit is a concave surface at shallow depth and closely parallel to the local configuration of the hillside. The log of hole 1, north of the pit, shows no extension of the bauxite into the hill, and data on shallow drill holes at the south end of the pit indicate that the bauxite and bauxitic clay do not extend farther to the south. Any extension of the bauxite would have to be west or east, more probably to the east toward the center of the concavity. The possibility of finding bauxite in commercial quantity in this deposit seems to be very slight, but holes at the two locations shown east of the pit (fig. 3) would give a good test. If commercial bauxite is found at these locations, a third hole should be drilled at the location indicated on the west side of the pit.

J. F. SMITH PROSPECT

A bauxite prospect comprising two shafts and a number of test pits and trenches occurs on the J. F. Smith farm, approximately two-thirds of a mile west of Summit, Tenn. (pl. 1). The prospect openings are at the northeast end of a long ridge at altitudes ranging approximately from 910 to 949 feet. The bauxite, discovered about 1936 by J. F. Smith, has not been mined. The shallow test pits (pl. 3) and the shaft near drill hole 15 were dug by Mr. Smith, and the 48-foot shaft northeast of hole 8 was sunk under his direction for the Kalbfleisch Chemical Co. Subsequently, a number of additional trenches were dug, and a few shallow holes were drilled by F. C. Thomas. During World War II, 24 holes were drilled in the cooperative exploration program of the Bureau of Mines and the Geological Survey—20 by a rotary drill and 4 by a churn drill. Some of the holes that were drilled with rotary equipment in the central part of the deposit had to be abandoned before completion when the walls caved and when blocks of chert in residual deposits at the outer margin could not be penetrated. The churn drill was used to deepen some of the holes that had been abandoned and to put down 4 additional holes. Because of the short time allotted for drilling, several of the abandoned holes could be not redrilled.

The drilling showed that the deposit of bauxite, bauxitic clay, and kaolin has approximately the form of a hollow cone, subelliptical in plan and V-shaped in cross section; the maximum length is 290 feet, maximum width is 130 feet, and proved depth is 190 feet (pl. 3). Around the outer rim of this ore body the thickness of the overburden ranges from 3 feet to a known maximum of 21.5 feet. The upper surface of the ore body descends abruptly inward from the rim, and the subconical depression thus formed is filled with overburden to a maximum known depth of 112 feet.

The maximum thickness of bauxite of grades B and C were found in the deepest hole, No. 29, which is apparently near the center of the deposit. The total thickness of bauxite and kaolinitic clay found in that hole was 78 feet—58 feet of grade C, 10 feet of very siliceous material of grade B, and, at the bottom, 10 feet of material nearly equally divided between grades D and D′. Following are a log of the hole and chemical analyses of samples of the bauxite.

Descriptive log of hole 29

Depth (feet)		
From	*To*	*Description*
0	2	Sandy loam and chert.
2	25	Sand, sandy clay, and chert.
25	41	Sandy clay and sand, light gray to white.
41	112	Sand, chert, and clay, buff, gray, and pink; cream and white below 104.5 ft.
112	149	Bauxite and bauxitic clay, compact, cream-colored to light-gray; granular material in grain to granule size.
149	165	Bauxite and bauxitic clay; a few dornicks and pisolites of hard bauxite.
165	175	Bauxite, light-gray to white; 5 percent pisolites and hard angular fragments of bauxite.
175	184	Bauxitic clay and bauxite, compact, cream-colored to light-gray with red stains; hard pisolites rare; soft ferruginous pisolites below 181 ft.
184	190	Clay and bauxitic clay, compact, sticky, red with irregular bands of cream and buff; hard angular bauxite fragments rare.
190	194	Sandy clay and chert.

Chemical analyses, hole 29

[Asterisk indicates not analyzed; McIntosh, 1949, p. 25]

Depth (feet)		Analyses (percent)				
From	To	Al_2O_3	Insoluble	Fe_2O_3	TiO_2	Ignition loss
112	115	46. 8	26. 3	0. 77	3. 65	21. 6
120	125	47. 7	22. 9	. 91	3. 80	23. 4
125	130	49. 7	22. 5	. 97	3. 10	23. 5
130	135	48. 1	24. 9	1. 06	3. 50	22. 2
135	140	48. 4	24. 1	. 91	3. 65	22. 3
140	145	50. 1	20. 7	. 91	3. 96	23. 8
145	150	50. 5	19. 8	. 89	3. 75	24. 5
150	155	49. 6	18. 0	. 91	3. 70	25. 1
155	160	49. 6	20. 2	. 91	3. 70	24. 4
160	*165	----------	----------	----------	----------	----------
165	170	53. 1	15. 4	1. 02	3. 65	26. 3
170	175	51. 1	16. 8	1. 00	3. 05	26. 0
175	180	50. 6	20. 7	1. 40	2. 70	23. 8
180	185	40. 4	33. 0	7. 13	2. 30	16. 4

Bauxite containing more than 50 percent alumina was also found in 5 additional holes, in each of which it was 10–15 feet thick; only in the western part of the deposit did bauxite of this description seem to be continuous. In hole 8 the bauxite is at a depth of 87–97 feet and averages 51.9 percent alumina and 21.4 percent silica; in hole 21 it is at a depth of 55–65 feet and averages 52.0 percent alumina and 18.1 percent silica; and in hole 25 it is at a depth of 60–65 feet and averages 51.1 percent alumina and 16.8 percent silica. The bauxite from these 3 holes is classed as grade C on the basis of its high silica content. In holes 17 and 23 some of the bauxite showed less than 15 percent silica and is therefore classed as grade B. The grade B bauxite in these holes is probably continuous through hole 8 as shown in section *B–B′*, plate 3, but the higher silica content in hole 8 causes this bauxite to be classed as grade C. Chemical analyses of samples from the cored intervals in holes 17 and 23 follow:

Chemical analyses, hole 17

[McIntosh, 1949, p. 14]

Depth (feet)		Analyses (percent)				
From	To	Al_2O_3	SiO_2	Fe_2O_3	TiO_2	Ignition loss
16. 5	20	33. 1	49. 8	2. 02	2. 3	12. 2
20	24	38. 4	57. 2	1. 48	2. 2	10. 3
24	30	31. 3	49. 9	3. 43	2. 9	11. 6
30	35	37. 3	41. 6	2. 82	3. 3	14. 3
35	39. 5	47. 7	22. 2	3. 90	3. 0	22. 6
39. 5	44	50. 8	15. 2	4. 57	2. 6	25. 7
44	49	51. 6	10. 8	6. 92	2. 9	26. 9
49	54	45. 7	21. 4	5. 85	3. 7	22. 6
54	59	45. 5	20. 1	11. 50	1. 0	20. 9
59	64	44. 5	19. 0	11. 40	2. 3	21. 7
64	69	36. 0	34. 4	11. 50	2. 5	14. 7
69	74	33. 7	35. 4	14. 90	2. 1	13. 2
74	78	34. 4	39. 1	11. 20	1. 6	12. 9
78	83	33. 3	42. 1	8. 87	1. 4	12. 7

Chemical analyses, hole 23

[McIntosh, 1949, p. 19]

Depth (feet)		Analyses (percent)				
From	To	Al_2O_3	SiO_2	Fe_2O_3	TiO_2	Ignition loss
24	29	25. 96	38. 55	23. 05	1. 49	11. 01
29	34	31. 88	38. 48	15. 75	1. 37	12. 57
34	39	32. 76	40. 27	12. 44	1. 30	12. 92
39	44	34. 43	36. 41	12. 44	1. 93	14. 90
44	49	48. 80	17. 07	5. 42	3. 48	24. 59
49	54	48. 18	20. 24	3. 94	3. 48	23. 83
54	59	51. 62	14. 04	4. 73	2. 90	26. 39
59	64	50. 75	17. 31	4. 15	2. 75	24. 54
64	69	51. 09	15. 02	4. 54	3. 07	25. 67
69	74	47. 71	19. 32	6. 40	2. 74	23. 48

Plate 4 shows isopachs drawn on the body as a whole. Although the resulting graphic representation expresses the measurements accurately, the actual steep-walled, funnellike shape of the body, as represented on plate 3 is not suggested by plate 4.

The probable extent of bauxite of grade B is shown in the sections on plate 3. All this ore is overlain and underlain by material of grade C and occurs within the part of the deposit that is lowest in iron.

The part of the body containing bauxite of grade C is a funnel-shaped sheet surrounded by bauxitic and kaolinitic clay and including within itself small masses of both higher and lower grade material. An isopach map of the body of bauxite of grade C, plate 4, shows that in general the body is thickest in the central, or deepest, part of the deposit. The most steeply dipping sectors of the sheet, where it curves around at its northern and western parts, are expressed by isopach patterns that give a false impression of local thickening.

The highest grade bauxite in the deposit is pisolitic, but the most common type is soft granular nonpisolitic bauxite which occurs principally as grain- to granule-size particles distributed throughout masses of semiplastic bauxitic clay. Rarely, the nonpisolitic bauxite occurs as pebble-sized pieces. Small inclusions of plastic clay occur irregularly throughout the deposit, most abundantly in the east one-third. Hard pisolitic bauxite and material containing free pisolites occur throughout the deposit and are exposed in the test pits on the north and west sides. Such material is more common, however, in the holes drilled on the north, west, and southwest sides. Extending into the ore body from the outer limits is a zone that has much higher iron content than the bauxite nearer the center. The approximate limit of this zone of ferruginous bauxite is shown on the cross sections in plate 3. Most of the high-iron material is bauxitic clay of grade D or kaolinitic clay of grade D′, although some of it is bauxite of grade C. On the basis of chemical analyses of selected samples from the surface and from drill holes, most, if not all, of the pisolitic bauxite is material of grade A, whereas analyses of nonpisolitic bauxite indicate that the best material of this type belongs in grade C. In the outer zone of the deposit, all types of bauxite are of inferior grade because of the high iron content. Scattered grains of fine to coarse sand occur in the soft bauxite and bauxitic clay, but most of the silica occurs in clay minerals or, if present as free silica, is too fine grained to be recognized by testing between the teeth. The pisolitic bauxite is not segregated according to any pattern that would permit profitable selective mining of this type alone, but most of it is included in a body of materials averaging grade C, the limits of which are shown by the maps.

Some exploratory drill holes had to be abandoned before reaching satisfactory total depths, and some uncertainty is therefore involved in the projected limits and grades of ore in the cross sections on plate 3. It is therefore recommended that, before any mining operations are started, four additional holes at locations shown be drilled for the purpose of checking the interpretations represented in the cross sections.

The data obtained from the drilling of the Smith bauxite deposit suggest that the bauxite and clay were deposited in a sinkhole. The unusual aspect of this deposit is its shape, which in cross section resembles a hollow cone surrounded by and filled with sandy cherty clay derived from dolomite. The authors believe that this arrangement was caused by the especially long and varied process of sinkhole formation during two major periods. During the first period, which was probably the longer, a sink was formed by solution of the limestone and dolomite where ground water moved through a local zone of high permeability. The fact that the greatest length of this deposit is in the direction of dip suggests that formation of the sink was controlled by joint system, or zone of shattering, cutting the strata in the direction of the dip but exhibiting little or no evidence of displacement by faulting. At the end of the first period, the roof collapsed, and the sink was filled, either at once by overlying clays or later by transported clays.

During the second period, regional uplift, climatic changes, diversion of ground water, or some other factor again permitted the passage of circulating waters. As a result of collapse or of removal of some of the clay fill through the bottom of the sink, a depression was formed at the top of the sink fill in which was deposited sand, sandy clay, and small-sized chert fragments that now form the plug of overburden in the central part of the body. The second period presumably closed when changing conditions reduced the drainage area of the sink or plugged the drainage channel. The clays which overlie the bauxite and form the plug in it are differentiated from the residual clays on plate 3 mainly by the amount of transportation involved, but they were probably derived from the weathering of carbonate rocks also.

As an alternative possibility, the observed distribution of bauxite, bauxitic clay, and kaolin surrounded by cherty clays residual from solution of the Copper Ridge Dolomite and covered by sandy variegated clays that contain small chert fragments can be visualized as resulting from a layer of bauxitic clay or kaolin overlain by sand and clay subsiding into a sink as the underlying carbonate rocks were removed by solution. The end result of such a process might account for the spatial distribution of the different materials found at the Smith deposit.

The known limits of the deposit indicate that it is almost bilaterally symmetrical, a distribution suggesting that the deepest part of the sink is close to the longitudinal axial plane. A drill hole in the exact center might show that the plug of overburden has a greater depth than is now believed or that it even extends entirely through the ore body.

No direct evidence was obtained regarding the age of the clays filling the sink or the period during which bauxite was formed. It may have formed before or after accumulation in the sinkhole, but the very small areal extent of all known Appalachian bauxite deposits and the usual absence of widespread bauxite float distant from them suggest that they all, including the Smith deposit, probably formed in sinkholes.

The ferruginous zone near the outer limit of the ore body (see pl. 3) at the Smith prospect may be the result of iron-bearing waters moving into the ore body from the enclosing clays and chert or it may represent the reverse process—a leaching of the iron in the central part of the body and redeposition near the outer margin. The relation between the permeability of the bauxite, bauxitic clay, and kaolin in the ore body and the permeability of the surrounding clays is unknown. The surface drainage seems to offer equal opportunity for movement of water in either direction. The fact that the bauxite of highest grade is thickest near the center of the body suggests to the authors that the leaching was from the center outward.

INDIAN MOUND DISTRICT

Bauxite occurs as lenses in several small deposits of kaolin in a rectangular area of about 3¾ square miles in the Indian Mound district, Stewart County, north-central Tennessee (fig. 1). These deposits and that in the Margerum district (Bergquist, 1965) in northwestern Alabama are the only occurrences of bauxite in the Highland Rim section of the Interior Low Plateaus physiographic province.

The kaolinitic clays of Stewart County were studied in 1932, prior to discovery of the bauxite, by G. I. Whitlach of the Tennessee Division of Geology. He described (unpub. data, about 1932) in detail the test pits that had been dug by J. C. Webb to that time. In 1932–33, the deposit containing bauxite was examined and described by Spain.[1] Interest in the Indian Mound district was revived in 1943, when the Geological Survey's study was undertaken; a decade later Wilson (1953) re-examined the area as part of his study of possible meteor craters in western Tennessee.

Kaolin and bauxite were discovered between 1931 and 1933 in the Indian Mound district in prospect pits and hand-auger borings. J. C. Webb first found bauxite 12 feet beneath the surface in a pit south of a tributary of the west fork of Butlers Branch, on property then belonging to C. A. Morey. The property was later purchased by Dr. J. Gant Gaither of Hopkinsville, Ky., who leased the land in 1934 to the Republic Mining and Manufacturing Co. (now Aluminum Co. of America). Bauxite was found by that company at various depths in three churn-drill holes and by the General Abrasive Co. in four additional holes bored in 1953. In the late 1930's a small amount of pisolitic bauxite was mined and was stockpiled in a shed on the Gaither property; a negligible amount was shipped to the Firestone Tire and Rubber Co. to be tested for possible use as a filler for rubber.

[1] E. L. Spain, 1933, A Pleistocene clay deposit near Indian Mound, Stewart County, Tenn.: Vanderbilt Univ. unpub. master's thesis.

GEOMORPHOLOGY

The broad interstream divides in the western part of the Highland Rim section of the Interior Low Plateaus physiographic province (Fenneman, 1938, p. 415–427) define the Highland Rim plateau, which coincides with the very slightly undulating Highland Rim peneplain. As described by Piper (1932, p. 17):

> The interstream tracts of the plateau are veined by ephemeral drainageways which have very flat longitudinal and transverse profiles and usually show a local relief of less than 50 feet. At some localities bowl-shaped or spoon-shaped depressions with surface drainage dot the otherwise featureless plain.

In the northern part of the Indian Mound district, especially north of U.S. Highway 79, the streams occupy shallow valleys, and sinks are not uncommon; thus the surface here is typical of the Highland Rim section. In the rest of the district, however, the valleys are steep walled, and the surface is deeply dissected by tributaries of the Cumberland River, principally Butlers Branch and its tributaries. Uplands in the northern and western parts of the district that rise 130–150 feet above Butlers Branch valley, to a maximum altitude of about 700 feet above sea level, probably represent the accordant summit levels of the Highland Rim peneplain. The presence of sinks is suggested by irregular and circular depressions on the rather flat surfaces of drainage divides, especially adjacent to the Cumberland River in the region southeast of Indian Mound and on a long, narrow north-south ridge, locally known as Long Ridge, that occupies the central part of the district and is parallel to Butlers Branch.

STRATIGRAPHY

MISSISSIPPIAN

The Warsaw Limestone of Mississippian age underlies the Indian Mound district. The limestone of this formation as exposed in stream valleys, close to water level, is generally thick bedded, hard, and compact. It crops out (1) along Cross Creek (fig. 4) and in continuous ledges from the mouth of Butlers Branch almost to the Will Austin house; (2) in small exposures in the upper reaches of Butlers Branch, along the base of the slope on the east side of the valley, about half a mile south of U.S. Highway 79; and (3) nearly a mile farther south, on the slope of the ridge above Blue Springs, as well as along the ravine of Cross Creek. The Warsaw is also exposed in the valley of Cherry Creek, along the Indian Mound road about a mile west of the area shown in figure 4.

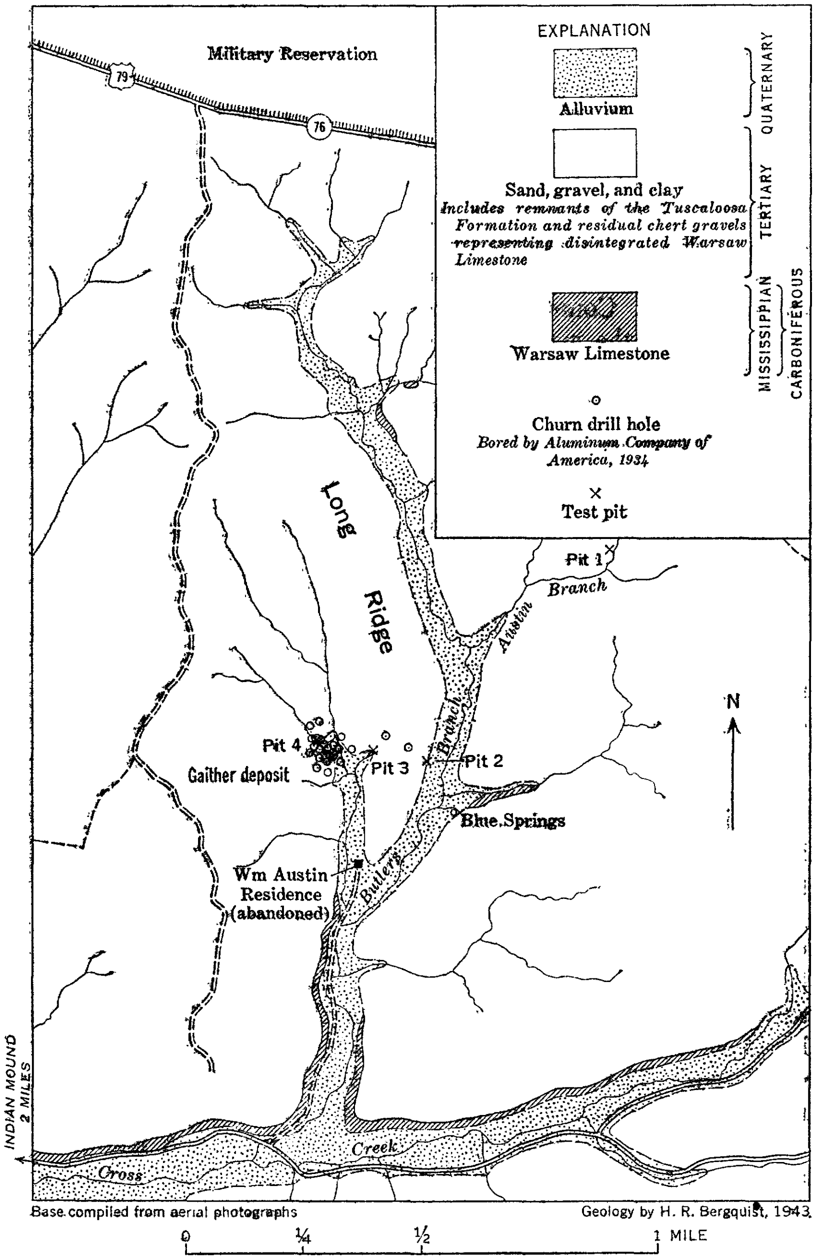

Figure 4.—Indian Mound bauxite district, Stewart County, Tenn.

CRETACEOUS AND YOUNGER GRAVELS

The uplands over much of the Indian Mound district and adjacent parts of Tennessee are mantled by unconsolidated sediments of probable Cretaceous and younger age—primarily sand and coarse gravel consisting of rounded pebbles and cobbles of chert. Angular residual chert, principally derived from the Warsaw Limestone, is also present. Some of the gravel deposits are probably remnants of the Tuscaloosa Formation (Upper Cretaceous), which crops out extensively in areas farther west. The Tuscaloosa and in places the overlying Eutaw Formation have been mapped by Piper (1932, pl. 4) in western and central Stewart County, but here and as far west as the Tennessee River most of the material of Cretaceous age has been removed by erosion. The surficial cover probably also includes rock debris that has accumulated intermittently during post-Cretaceous episodes of uplift and erosion.

PALEOCENE AND EOCENE

The bauxite and kaolin deposits of the Indian Mound district as well as the associated sand, clay, and lignite are considered by the authors to be of Paleocene and Eocene age. This district includes 2 of 4 localities in Stewart County where, according to Wilson (1953), similar materials occur in small sedimentary deposits of Wilcox age that accumulated in "craters" whose origin he attributed to the "impact and resulting explosion of fragments of a meteor that had fallen in post-Eutaw, pre-Wilcox time." Wilson reported that heavy-mineral assemblages in the argillaceous materials at all four of these localities are similar to one another and that spores that were identified by E. S. Barghoorn show the associated lignite to be of early Tertiary (pre-Miocene) age.

According to Wilson, "the gross lithology of the clay, lignite, and sand is identical with that of the Wilcox beds of West Tennessee about 35 miles west of Indian Mound." His belief was that these Wilcox sediments were once "continuous with those of West Tennessee; if this is correct, the latter extended much farther east than previously postulated." The sediments are considered by the authors of the present report to represent outliers of the thin and irregular east margin of sediments of late Midway to early Wilcox age. A kaolin deposit comparable to the deposits in this district, but occurring farther southwest, in Carroll County, was shown by Whitlatch and Gildersleeve (1946) to be within an outlier of the Ackerman Formation (Eocene), protected from subsequent Eocene erosion by its position in a shallow depression in the top of the underlying Porters Creek Clay (Paleocene).

QUATERNARY AND RECENT

The valley floors in the district for the most part are covered by alluvial deposits of Quaternary and Recent origin, consisting of bedded gravel and sandy clay. They are exposed to a depth of a few feet along stream channels.

GAITHER BAUXITE AND KAOLIN DEPOSIT

The Gaither deposit is along the west fork of Butlers Branch, about three-eighths of a mile north of the junction of the west fork with the main stream (fig. 4). Pit 4, the discovery pit near the west side of the deposit, is approximately a quarter of a mile north-northwest of the Will Austin house and 200 feet west of the west fork of Butlers Branch (fig. 4), near the base of the south valley wall of a small east-flowing tributary. The deposit of kaolin and bauxite lies principally in the valley of the west fork and its east-flowing tributary but also extends to the southwest. The altitude in the vicinity of the deposit ranges from approximately 520 to 550 feet above sea level.

The kaolin body in which the bauxite occurs as small lenses is probably about 300 feet long in an east-west direction, 200 feet wide, and more than 130 feet thick in the western part. Along the margins the clay thins abruptly and grades into sand. The bauxite lenses seem to be less than 10 feet thick and 100 feet or less in greatest areal dimension. Available data from test pits dug by J. C. Webb and churn-drill holes by the Republic Mining and Manufacturing Co. and by the General Abrasive Co., Inc., indicate several small lenses of bauxite between a depth of 12 and 100 feet. The locations of pits and drill holes are shown on plate 5. The positions of the kaolin body and the bauxite lenses are shown in cross sections.

Pit 4 was dug to a depth of 40 feet and deepened by hand auger to a depth of 127 feet. It was abandoned in clay. Five feet of bauxite was penetrated at a depth of 12 feet beneath clay and loam; beneath the bauxite 8 feet of titanium-rich kaolin was logged. This material was succeeded by 64 feet of kaolin that contained organic matter and was stained by iron in the upper part but was white in the lower part.

Bauxite was found in three of the test holes drilled by the Republic Mining and Manufacturing Co. In hole A1, drilled about 25 feet S. 10° E. of pit 4, 6 feet of bauxite and clay was penetrated at a depth of 72–78 feet; the upper 2-foot interval contained 49.91 percent alumina, 18.16 percent silica, and 7.25 percent titania; the lower 4 feet contained about 49 percent alumina, 23.24 percent silica, and 4.50 percent titania.

Hole C3, drilled 75 feet S. 58° E. of pit 4, penetrated 8 feet of bauxite beneath 30 feet of clay at a depth of 64–72 feet and 10 feet of bauxite at a depth of 88–98 feet. Some of the bauxite of each lens is extremely low in silica (4.6 to 7.0 percent), and all of it contains less than 1 percent iron oxide. Chemical analyses, in percent, of the bauxite lenses and the underlying clay are as follows:

Chemical analyses, hole C3, Gaither deposit

[Asterisk indicates clay, not analyzed; analyzed by Aluminum Co. of America]

Depth (feet)		Analyses (percent)					
From	To	Al_2O_3	SiO_2	Fe_2O_3	FeO	TiO_2	H_2O
64	66	50. 59	18. 49	0. 85	0. 12	6. 30	23. 77
66	70	54. 53	11. 35	. 65	. 12	5. 60	27. 87
70	72	53. 09	14. 55	. 65	. 12	5. 50	26. 21
72	*88						
88	90	49. 83	22. 65	. 90	. 12	6. 65	22. 65
90	94	57. 53	7. 07	. 75	. 12	7. 07	28. 65
94	98	50. 75	18. 85	. 80	. 12	5. 65	18. 85
98	*103						
103	106	40. 90	38. 70	1. 05	. 24	2. 95	16. 40

Hole D2, drilled 215 feet S. 83° E. of pit 4, penetrated 9 feet of bauxite. Samples from 30 to 36 feet below the surface contained 56–61 percent alumina, 2.32–9.91 percent silica, 0.8–1.0 percent iron oxide, and 3.5–4.8 percent titania. This hole is near the east end of the kaolin body, where it is only 70 feet thick, and the lower 30 feet is somewhat sandy.

The approximate locations of holes drilled by General Abrasive Co., Inc., are also shown on plate 5. Their exact location with respect to the earlier drilling is not known, but the materials penetrated suggest that the locations shown are reasonably correct. A company plat of this drilling also showed the location of a hole drilled previous to their explorations. The locations of the holes drilled by General Abrasive Co. are shown on plate 5 on the premise that hole C2 is the "old hole" shown on their drilling plat.

The greatest thickness of bauxite and kaolin in this drilling was found in hole G2, which went through white kaolin from a depth of 10 to 22 feet, kaolin mixed with lignite or carbonaceous clay from 22 to 58 feet, and pisolitic bauxite from 58 to 72 feet. Two feet of sand was penetrated below this at the bottom of the hole.

Bauxite was also found in three other holes. In hole G4, white kaolin extends from a depth of 10 to 140 feet except for lenses of bauxite 24 to 28 feet and bauxitic clay at 28 to 32 feet. In hole G5, white kaolin and lignitic or carbonaceous clay extend from a depth of 10 to 106 feet; some pisolitic bauxite occurs at 87 to 90 feet. In hole G7, white kaolin extends from a depth of 25 to 50 feet; the lower 4 feet is somewhat sandy, and an interval from 27 to 34 feet contains some pisolitic bauxite. Nearly all holes in this drilling program were bottomed in fine white sand, although hole G5 at 106 feet and hole G6 at 100 feet bottomed in clay.

As can be seen from a comparison of these holes with the cross sections on plate 5, if the holes of the Republic Mining Co. and the General Abrasive Co. are correctly located with respect to each other, the bauxite is somewhat more lenticular and spotty than shown on the plate. The absence of bauxite in other test holes also indicates its erratic occurrence as lentils or beds of irregular extent within the kaolinitic clay.

Bauxite found in pit 4 was reported (Tennessee Valley Authority, unpub. data, 1934) to be soft and clayey and to contain "horses" of clay similar to the material that overlies it. Large irregular pisolites, some as much as 1½ inches in longest diameter, are imbedded in a soft matrix from which they fall free. Most of the pisolites lack concentric structures.

Chemical analyses, in percent, of a sample of bauxite from hole G2 were made by General Abrasive Co. to determine which part contained the most alumina. The results are as follows:

	Whole sample	*Pisolites only*	*Matrix only*
Al_2O_3[1]	47.25	61.40	39.98
SiO_2	23.32	1.54	32.76
Fe_2O_3	.55	.30	.62
TiO_2	8.80	4.70	11.20
H_2O	20.08	32.06	15.44

[1] Calculated by difference, E. F. Overstreet.

The analyses indicate that the matrix is largely kaolinite with minor gibbsite and that the pisolites are almost entirely gibbsite. The titania content, although characteristically high throughout the deposit, is much higher in the matrix than in the pisolites. The Geological Survey's analyses, in percent, of pisolites and matrix from pit 4 show similar results, as follows:

	Pisolites	*Soft matrix*
Al_2O_3	56.80	41.31
SiO_2	6.54	31.08
Fe_2O_3	.10	1.26
TiO_2	6.38	7.99
H_2O-	.31	.51
H_2O+	30.34	17.06
Total	100.47	99.21

The relation between the bauxite and kaolin is not clear. Burchard (Thoenen and Burchard, 1941, p. 26) considered the bauxite near the surface in the discovery pit 4 to have formed by weathering along a fracture plane that cuts vertically through the clay beds. Joints may have formed at several places by compaction or movement of the clay body, and weathering may have proceeded along these avenues. Subsidence after the bauxite was formed also may have produced the spotty distribution of bauxite and the "horses" of kaolin in the bauxite.

East of the kaolin lens only sand and gravel was found in drilling; bedrock is at depths of 90–130 feet. South and southwest of the lens mainly sand was penetrated; depth to bedrock is probably 100–140 feet. The probable size of the sinkhole at a depth of 100 feet is indicated by the dotted line on plate 5.

Drill hole D4 in the northeast and deepest part of the deposit went through 263 feet of material, chiefly sand and lignite. Such a thickness of sediments in a small area can be mostly readily explained as deposition in a sinkhole. Karst topography on a Cretaceous or early Tertiary plain would readily provide catchment areas for sand and clay. Gradual enlargement of a basin, subsidence of the deposit, and (or) collapse of the roof of a cavern beneath the basin would allow the accumulation of a great thickness of sediments. The origin of the Gaither deposit is attributed to a combination of these processes.

Valley fill as an explanation of the origin of the Gaither deposit it untenable: the bottom of the deposit is at least 50 feet below bedrock in the Cumberland River 6 or 7 miles to the southwest, and outcrops along Cross Creek and Butlers Branch do not indicate that their valleys were ever at the requisite level—several hundred feet deeper than they are at present.

Prospecting for bauxite in other stream valleys near the Gaither deposit and along the Cumberland River proved fruitless. Small deposits of kaolinitic clay, exposed in test pits 1 and 2 on the opposite side of Long Ridge from the Gaither deposit, do not seen to have any great vertical or lateral extent, nor do they connect with the Gaither deposit.

The Gaither kaolin deposit is small, but the overburden is slight. If an economical method of recovering alumina from kaolinitic clays is developed or if both kaolin and bauxite could be marketed together for any purpose, the entire deposit could be readily mined, and the material could be easily transported by truck to the railroad at Clarksville.

OTHER CLAY DEPOSITS

A small isolated lens of white grit-free kaolin was found by J. C. Webb in 1931 or 1932 near the upper end of Austin Branch (fig. 4, pit 1). It is about 2,000 feet northeast of the junction of Austin Branch and Butlers Branch and about 50 feet above the valley floor. Webb dug shallow test pit 1 and deepened it by auger drilling to a depth of 30 feet. The deposit is extremely small in lateral extent, as shown by the absence of clay in pits and test holes sunk at distances of 20–100 feet. Spain [2] considered that this kaolinitic clay was part of the deposit on the Gaither property and that erosion of a large amount of material had left the clay as an isolated remnant. The later test-hole records of the Republic Mining and Manufacturing Co., however, show that the area between the two places is underlain by sand and lignitic material, and, in addition, that the ridge areas are largely sand and gravel. An analysis of clay from this pit, as cited by Spain,[2] shows 35.58 percent Al_2O_3, 46.88 percent SiO_2, and 3.60 percent TiO_2.

Another very small lens of kaolin is exposed in pit 2 on the west edge of the valley of Butlers Branch, approximately 650 feet northwest of Blue Springs and 17 feet above the stream. According to G. I. Whitlatch (written commun., 1932), 7 feet of white kaolin, iron-strained in places, was exposed beneath 3 feet of cherty clay. Subsequent drilling revealed beneath the clay 12 feet of yellow sand underlain by at least 23 feet of sandy lignite. A test hole at the same altitude but 250 feet N. 25° W. of the pit went through 25 feet of reddish-yellow sand but no clay.

Pit 3 (fig. 4) was dug by J. C. Webb in the floor of a small gully 500 feet west of pit 2 and approximately an equal distance east of the main kaolin lens. This pit penetrated 4 feet of residual cherty clay and chert and 19 feet of compact dark-gray sandy clay but no kaolin.

Cherty clays derived from the weathering of the Warsaw Limestone and lenses or stringers of transported ferruginous gray and white sandy clay are exposed at a few places along the stream valleys or in the beds of the streams. The clays derived from the limestone are white and almost free from iron oxide stains. They contain partly altered chert fragments or the outlines of altered chert blocks, and for this reason they can be readily distinguished in the field from kaolin deposits.

ELIZABETHTON DISTRICT

The geology and bauxite deposits of the Elizabethton district have been described in reports by King and Ferguson (1960) and by King, Ferguson, Craig, and Rodgers (1944) as part of a study of a larger area in northeastern Tennessee. For detailed information on the district, the reader is referred to these two publications. A résumé of the geology and the mines in the two known bauxite deposits in the district follows.

Two deposits of bauxite, together with a few prospects for manganese and iron, occur on the southwest end of Holston Mountain, about

[2] See footnote, p. 27.

2 miles north and northeast of Elizabethton, Carter County, in what is designated the Elizabethton district (fig. 1). The bauxite deposits are isolated with respect to bauxite deposits elsewhere in the Southeastern United States. They are about 200 miles northeast of the Chattanooga district, Tennessee, and about 150 miles southwest of the closest deposits in Virginia. All three districts are in the Valley and Ridge province.

The Elizabethton district is underlain by sedimentary rocks ranging in age from Early Cambrian to Ordovician. The Lower Cambrian formations, capping Holston Mountain, are thrust northwestward over rocks of younger Paleozoic age which extend into the Holston River valley to the northwest. Only formations of Early Cambrian age in the thrust sheet are pertinent to a study of mineral resources of the district.

Nine deposits of red and yellow shaly clay and kaolinitic clay of probable Tertiary age were mapped in the area underlain by the Shady Dolomite of Early Cambrian age. The bauxite occurs in two of these deposits. The clays and the bauxite are considered to have been deposited in sinkholes and solution channels in the Shady prior to the accumulation of the residual clay which now blankets the dolomite.

Mines that have been opened in both deposits of bauxite are the Watauga and the Red Bird Hill mines. The Watauga mine is at an altitude of 2,160 feet, at the inner margin of a flat slope of a spur trending southwestward off Holston Mountain. Bauxite Hollow separates the Watauga mine from the Red Bird Hill mine less than 1,000 yards to the southeast, on a similar flat-topped spur and at an altitude of 2,340 feet.

The Watauga mine was in operation from 1912 until 1922. Total production for the period was approximately 20,000 long tons of ore. The workings consist of a large badly slumped opencut about 250 feet in an east-west direction, 150 feet north-south, and about 50 feet deep at the deepest end. It drains to the west and holds no water. West of the cut is the portal of underground workings that extend 370 feet beneath the opencut. Eight crosscuts extend for short distances north and south of the main drift. The longest is about 45 feet long. Three shafts have been put down from the opencut to the drift, but by 1954 all were slumped and inaccessible. Available data indicate that only an extremely small reserve of bauxite containing more than 53 percent alumina remains in the deposit. A somewhat larger tonnage of bauxite containing from 40 to 53 percent alumina is probably also present.

The Red Bird Hill mine consists of a short adit and an opencut about 75 feet long, 40 feet wide, and a maximum of 20 feet deep. The cut opens to the east. The walls of the cut were badly slumped in 1942, and the adit was caved. There has been no known production from the mine despite the size of the opencut. Available information from prospecting does not indicate an ore body of appreciable size.

Manganese and iron minerals occur in three types of deposits in the district: in residual clays, in breccia deposits, and in bedded deposits. The chief manganese minerals are wad, psilomelane, and pyrolusite. The chief iron minerals are limonite and hematite.

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