GEORGIA

STATE DIVISION OF CONSERVATION

DEPARTMENT OF MINES, MINING AND GEOLOGY

GARLAND PEYTON, Director

THE GEOLOGICAL SURVEY

Bulletin Number 51

SILLIMANITE AND MASSIVE KYANITE IN GEORGIA

(A Preliminary Report)

By

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and

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(With discussion of concentration by J. Bruce Clemmer, Carl Rampacek, and B. H. Clemmons, and refractory properties by T. N. McVay)

Published in Cooperation with the Tennessee Valley Authority

ATLANTA

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II

Residual boulders of massive kyanite, Pickens County.

LETTER OF TRANSMITTAL

Department of Mines, Mining and Geology

Atlanta, March 27, 1945

His Excellency, Ellis Arnall, Governor
Commissioner Ex-Officio, State Division of Conservation
Sir:

I have the honor to submit herewith Georgia Geological Survey Bulletin No. 51, "Sillimanite and Massive Kyanite in Georgia," by Dr. A. S. Furcron, Assistant State Geologist, and Kefton H. Teague, Assistant Geologist of the Tennessee Valley Authority. This bulletin has been prepared and published in cooperation with the Tennessee Valley Authority and the U. S. Bureau of Mines.

The report announces the discovery in Georgia of two economically-important refractory minerals in commercial quantities, namely, sillimanite and massive kyanite. An extensive deposit of sillimanite was discovered in the course of the work in Hart, Elbert, and Madison counties, and deposits of massive kyanite previously known only from India were discovered in Cherokee, Pickens, and Dawson counties. Both of these minerals are regarded as essential ingredients in mixtures from which superduty refractory furnace linings and special electrical porcelains are manufactured. These deposits not only constitute our first discovery of domestic supplies of these raw materials in worthwhile quantities, but when considered in combination with Georgia's kaolins and bauxitic clays they are believed to constitute the basis of probable new manufacturing industries in Georgia.

It is desired to point out the fact that this bulletin illustrates more nearly the ideal arrangement for conducting federal-state cooperative projects. In the first place, without the cooperation of the Commerce Department of the Tennessee Valley Authority, it would have been impracticable to consider launching the project. The Tennessee Valley Authority cooperated by making available a geologist to work with a geologist from this office in conducting the field work, and assisted in publication. The U. S. Bureau of Mines added materially to the practical commercial value of the bulletin by contributing chapters setting forth the results of their research on the beneficiation and utilization of both sillimanite and kyanite.

Respectfully,
GARLAND PEYTON
Director.

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ABSTRACT

The report discusses deposits of sillimanite and massive kyanite in Georgia. Part one of the report describes sillimanite deposits recently discovered in Hart, Elbert, and Madison counties, Georgia, and from Towns County, Georgia, and Clay County, North Carolina. The report also covers the geology, classification, distribution, uses, and other economic features of the mineral. The sillimanite in the Georgia-North Carolina area was sampled by the writers, and concentrates were prepared by the Department of Chemical Engineering of the Tennessee Valley Authority.

Large samples from the deposits in Hart, Elbert, and Madison counties were referred to the Southern Experiment Station, Department of Interior, U. S. Bureau of Mines, where sillimanite concentrates were prepared; tests for refractory values were conducted at the Electrotechnical Laboratory of the Bureau of Mines at Norris, Tennessee. Preliminary concentration indicated that this sillimanite ore is amenable to flotation. Chemical and screen analysis of the Georgia and South Carolina sillimanite indicate that the ore from the two states is very similar. Firing tests conducted by the Electrotechnical Laboratory showed that refractories made of sillimanite meet both the reheat specifications of the American Society for Testing Materials and those of the United States Navy for superduty refractories. In high temperature load-tests, sillimanite brick have an excellent load-carrying capacity at elevated temperatures, and in the alumina-silica class are probably exceeded only by the electrocast corundum-mullite.

The second part of the report deals with deposits of massive kyanite recently discovered by the writers in Cherokee, Pickens, Dawson, and Gilmer counties. This section of the report does not duplicate data published in previous Bulletin 21*, of the Georgia Geological Survey.

Massive kyanite deposits occur in a complex of earlier pre-Cambrian rocks (Amicalola gneiss) which occur in a triangular-shaped area at the southern end of the Blue Ridge

* References are at the end of the report.

south of Mt. Oglethorpe. Unconformable over this complex is an extensive series of biotite gneisses, graywackes, quartzites, and graphitic rocks of later pre-Cambrian age. The basal portion of this series (Oglethorpe formation) is well exposed northwest of Mt. Oglethorpe. Later facies of this series are mapped west of Nelson and Tate. Areas of marble (Murphy marble) of probable pre-Cambrian age are mapped and described.

The pre-Cambrian formations of the area are profoundly affected by an overthrust which extends northeastward from the vicinity of Canton to a locality northeast of Dawsonville. The pre-Cambrian rocks north of this fault line are greatly sheared. At the southern end of the Blue Ridge, Amicalola gneiss and Oglethorpe formation are thrust westward. Along the west side of this overthrust there is an extensive area of sheared rock which includes many of the deposits of Murphy marble (Plate 3).

Under the discussion of massive kyanite the report describes briefly the occurrence of ore similar to that now imported into this country from India. Deposits of kyanite are classified, and the size, distribution, origin, and geology of deposits of the massive type in this part of the State are discussed. Samples of the kyanite ore were sent to the Electrotechnical Laboratory, Norris, Tennessee, where brick samples were made and given the preliminary standard tests for refractories. In general, satisfactory "superduty" refractories were made from the Georgia massive kyanite samples. Mineral stains and inclusions in the massive kyanite cause from 10 to 33 per cent loss during calcination. This loss is more pronounced in the smaller lumps.

A coarse, compact, and sturdy grog was obtained from the Georgia mineral, and this was similar to that furnished by the fibrous and coarse crystalline grades of "India" kyanite but not equal to the best "India" corundum-kyanite. Grog of the Georgia massive quality has never been obtained from other domestic kyanite by direct calcination of original lumps. A coarse grog is desirable for quality of ware, ease of manufacturing, and in the production of spall-resistant refractories.

Standard size brick made from the Georgia kyanite were lighter in weight and higher in pore space than those made from the "India" corundum-kyanite. The sample brick when fired to 1600° C. met the A.S.T.M. reheat specifications for "superduty" fire brick, and it is possible that they can be made sufficiently volume-constant to meet the Navy specifications. The longer firing period in commercial kilns may permit a temperature lower than 1600° C. which was used in laboratory practice. The load resistance of the Georgia kyanite sample brick at high temperature was very satisfactory.

FIELD WORK AND ACKNOWLEDGMENTS

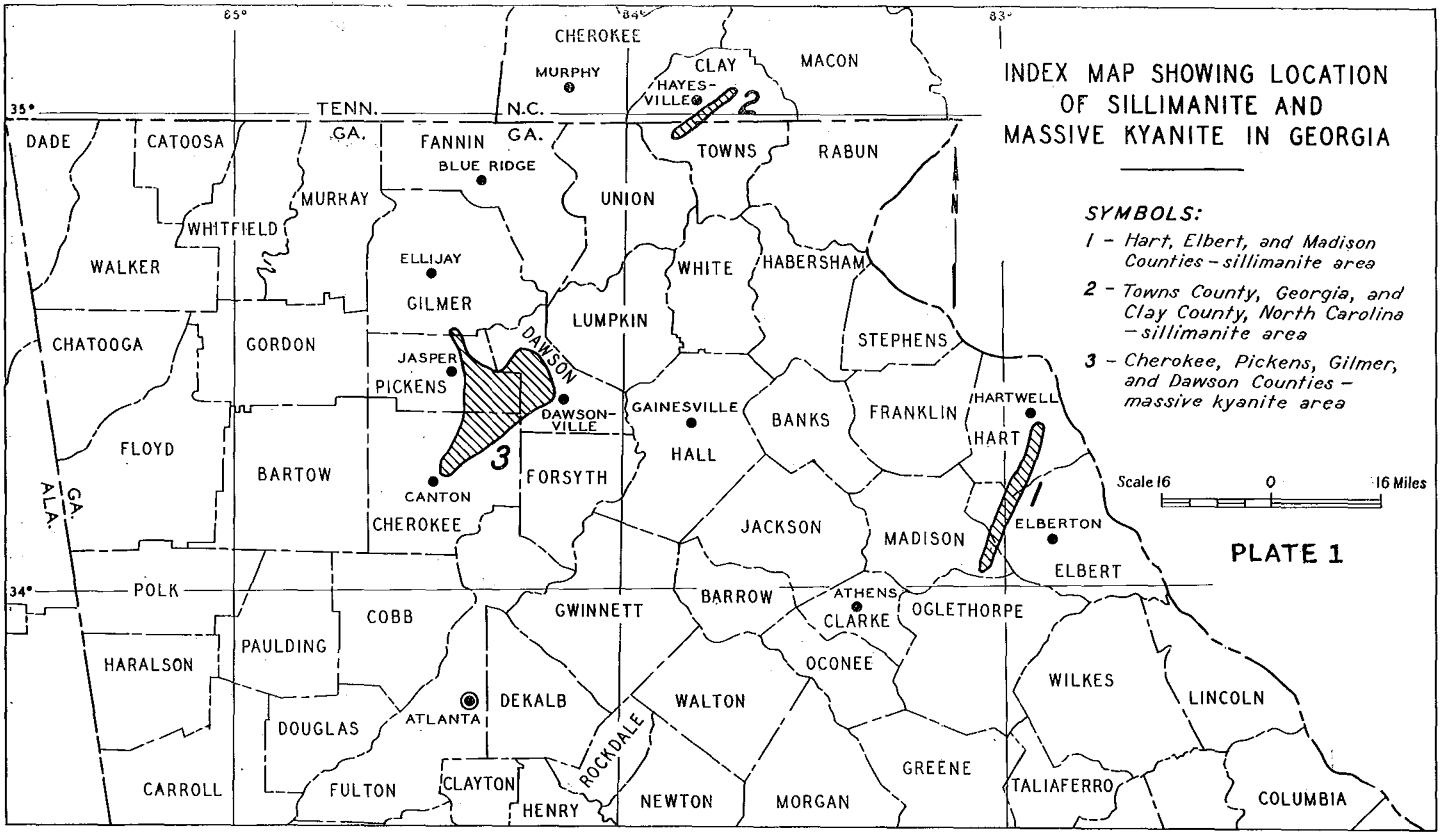
This work presents results of a continuation of cooperative projects between the Georgia Department of Mines, Mining, and Geology and the Tennessee Valley Authority upon the investigations of strategic minerals in Georgia. About three months of field work was done by the writers in mapping and collecting data for the report during 1944. The writers are preparing another paper upon the structure and stratigraphy of the Murphy marble belt in Georgia and North Carolina.

The writers wish to express their appreciation for the encouragement and assistance of Captain Garland Peyton, Director, Georgia Department of Mines, Mining, and Geology, and of Mr. H. S. Rankin, Senior Mining Engineer, Commerce Department, Tennessee Valley Authority. Mr. and Mrs. George W. Stose spent several days in the field with the writers where they reviewed the geologic map of the massive kyanite area, making valuable comments and criticisms.

The Department of Chemical Engineering of the Tennessee Valley Authority prepared numerous thin sections of the rocks of the region; also they prepared concentrates of sillimanite collected in the Davy Mountain area. Dr. James L. Calver and W. T. McDaniel, Jr., Geologists for the Tennessee Valley Authority, traced the Davy Mountain sillimanite belt in North Carolina to a point east of Hayesville. The maps used in the report were prepared by the Drafting Department of the Tennessee Valley Authority under the supervision of the writers.

The writers wish to acknowledge the assistance of members of the staff of the United States Department of the Interior, Bureau of Mines, at the Southern Experiment Station, Tuscaloosa, Alabama, and the Electrotechnical Laboratory, Norris, Tennessee. A concentrate of the Hart County ore was prepared at the Southern Experiment Station, Will H. Coghill, supervising engineer, under the direction of Mr. J. Bruce Clemmer, Metallurgist, assisted by B. H. Clemmons and Carl Rampacek. The refractory values of the massive kyanite and sillimanite were determined at the Electrotechnical Laboratory under the supervision of Dr. Hewitt Wilson. Dr. T. N. McVay of the Southern Experiment Station and his assistants prepared the sections of the report which deal with the refractory values of the massive kyanite and sillimanite.

Dr. M. V. Denny of the Mineralogical Laboratory of the University of Michigan checked the writers' identifications of sillimanite and kyanite by means of powder photographs.


INDEX MAP SHOWING LOCATION OF SILLIMANITE AND MASSIVE KYANITE IN GEORGIA
SYMBOLS:
1 – Hart, Elbert, and Madison Counties – sillimanite area
2 – Towns County, Georgia, and Clay County, North Carolina – sillimanite area
3 – Cherokee, Pickens, Gilmer, and Dawson Counties – massive kyanite area
Scale 16 0 16 Miles
PLATE 1
85°
84°
83°
35°
34°
TENN.
GA.
N.C.
GA.
GA.
ALA.
N
CHEROKEE
MURPHY
CLAY
HAYES-VILLE
MACON
DADE
CATOOSA
FANNIN
BLUE RIDGE
TOWNS
RABUN
MURRAY
UNION
WHITFIELD
WALKER
ELLIJAY
WHITE
HABERSHAM
GILMER
LUMPKIN
CHATOOGA
GORDON
STEPHENS
DAWSON
JASPER
PICKENS
DAWSON-VILLE
GAINESVILLE
HARTWELL
BANKS
FRANKLIN
HART
FLOYD
HALL
BARTOW
FORSYTH
CANTON
CHEROKEE
JACKSON
MADISON
ELBERTON
ELBERT
POLK
BARROW
ATHENS
GWINNETT
CLARKE
OGLETHORPE
COBB
PAULDING
HARALSON
OCONEE
WILKES
DEKALB
WALTON
LINCOLN
ATLANTA
DOUGLAS
ROCKDALE
GREENE
CARROLL
FULTON
CLAYTON
HENRY
NEWTON
MORGAN
TALIAFERRO
COLUMBIA

PART I

SILLIMANITE

PHYSICAL PROPERTIES OF SILLIMANITE

The following is a brief general description of the mineral sillimanite. For a more complete discussion of the physical and chemical properties the reader is referred to the standard works on mineralogy. Sillimanite has the theoretical chemical composition Al_2SiO_5, and when heated above 1600° C. converts to a mixture of mullite ($3Al_2O_3.2SiO_2$), and silica or siliceous glass. This mixture has a specific gravity of about 3.15.

Sillimanite has a hardness of 6 to 7, vitreous, silky to subadamantine luster, specific gravity of 3.2 to 3.3, and is gray to bluish-gray in color. Under the binocular, the crystals are transparent. The mineral may occur as dense, fibrous mats (fibrolite) composed of fibrous, sometimes radiating hair-like crystals in schist where it is associated with igneous intrusions. Examples of this type of material are some of the Davy Mountain deposits, and numerous small deposits scattered throughout the schists of North Georgia. Sillimanite also occur as bundles of crystals disseminated in biotite schist, as noted in the Hart-Elbert-Madison County area.

Sillimanite may often be confused in the field with the amphiboles, especially tremolite, but these minerals may be separated on the basis of hardness and specific gravity, since sillimanite is considerably harder and is also heavier. The index of refraction of sillimanite is much greater than that of tremolite, sillimanite having an index of refraction of from 1.659 to 1.68, whereas tremolite has an index of refraction of 1.602 to 1.650.

In most sillimanite deposits more or less sericitization has taken place, but the presence of this type of alteration may be readily detected in the field by a test for hardness.

USES OF SILLIMANITE

For the past thirty years there has been a tendency in the ceramic and metallurgical industries towards the use of raw materials which can withstand higher temperatures in the manufacture of their products. At present a number of high grade alumina products are made from several sources including: the crystalline corundum produced in the electric furnace from bauxite, corundum-mullite electrocast refractories made from a mixture of bauxite and fireclay, mullite refractories made from domestic and "India" kyanite, and small amounts made from western domestic andalusite, as well as a little made from South Carolina topaz.

One of the best qualified minerals for high temperature refractories is sillimanite. The mineral has an advantageous characteristic over "India" kyanite and topaz in that it does not require pre-calcining before incorporation into a body for service, at least, below 1600° C. Although sillimanite deposits are known in Australia, India, and Africa, industry has not yet accepted it as an ore. Domestic sillimanite ores must be concentrated, also it will be necessary to remove iron stains before the concentrates can be used in the highest grade refractories; however, few serious attempts to beneficiate the ore have been made.

Some of the more prominent potential uses for sillimanite are: porcelain for spark plugs, high grade refractory bricks, crucibles, saggers of all types, boiler linings, high temperature cements, linings for indirect-arc and heat treating furnaces, pyrometer tubes, glass tank blocks, et cetera.

OCCURRENCE OF SILLIMANITE

Sillimanite in Foreign Countries

Sillimanite has been observed from many localities in the world, but most of the deposits discovered thus far have been small and non-commercial. The mineral is not infrequently encountered as small radiating prisms in metamorphic rocks, especially schists. In the field it is easily overlooked, thus it may be more abundant than is generally thought.

Rather large deposits of the mineral have been reported from Mongmaweit Village at Khasi Hills, Assam, and from Pipra, Rewa, India. A minimum reserve of 182,600 tons is estimated for these two localities.[4] The Assam deposits are very inaccessible. The deposits generally consist of massive sillimanite with a little corundum in highly aluminous rocks such as sillimanite-quartz schists interbedded with cordierite-biotite-quartz microcline gneiss. Thirteen different deposits occurring over a belt 3 miles long and a mile wide were discovered by Dunn during the field season of 1927.[18]

The Pipra deposits occur in pre-Cambrian rocks in Rewa State, Central India, where in 1927 the ore was transported by ox cart 120 miles to Mirzapur. Most of the rock consists of sillimanite schist containing local segregations of corundum-sillimanite.

Sillimanite has been reported by Simpson[22] from the north-western shore of Weelhamby Lake in Ninghanboun Hills of Western Australia. The rock is coarsely granular quartz with dense bundles of sillimanite fibers. Sericite, muscovite, biotite, garnet, feldspar, chlorite, and some andalusite are associated minerals. In another locality near by, sillimanite occurs in granular quartzite. Long narrow lenses of andalusite-muscovite schist are interbedded with the sediments associated with the sillimanite, and large angular pebbles of pure crystalline andalusite up to 50 pounds in weight occur which were derived from highly quartzose pegmatites which cut hornblende schist.

Other sillimanite deposits from western Australia have been described, and commercial deposits are known from the vicinity of Clackline [23] where it occurs in a primary clay which has been used for over 30 years in the manufacture of fire-bricks. It is found in seams as thin plates and small lenticular "eyes" of almost pure sillimanite, which mineral constitutes about 5 per cent of the entire mass. Simpson concludes from his observations, "that the greater part of clay used in the making of firebricks at Clackline is a highly kaolinized biotite schist of the Chittering pre-Cambrian series. Originally this rock was probably highly glauconitic shale."[23]

The Board of Economic Warfare recently investigated a sillimanite deposit from the Broken Hill District, New South Wales. Sharpstone states*: "By way of explanation may we state that at no time have we been especially interested in the sillimanite deposit in question since, when we did have a pur-

* Sharpstone, David C., personal communication, April 25, 1944

chase directive, it specifically called for Indian kyanite. Furthermore, shipments from Australia received by Philipp Brothers, Incorporated, 70 Pine Street, New York, and by Chas. Taylor Sons, Cincinnati, proved that the material could not be considered a substitute for Indian kyanite. To my knowledge Philipp Brothers received a shipment of 60 tons, and they report that it turned out useless; Charles Taylor Sons received a two-hundred ton shipment, and they state that it is not practical to adapt it to the uses of Indian kyanite."

Sillimanite in the United States

In the United States, small unimportant deposits have been reported from several counties in California, from Massachusetts, Connecticut, New York, Pennsylvania, Delaware, Virginia, North Carolina, etc.; a few tons of sillimanite are reported to have been produced from North Dakota. Forrester[5] has described a sillimanite deposit near Troy, Latah County, Idaho. A report on sillimanite deposits in the Monadnock Quadrangle, New Hampshire, by Mrs. Billings[2] has been published recently. The deposits appear to be small, but descriptions of them in the report indicate that they resemble the ones in Hart, Elbert, and Madison counties, Georgia.

About a year ago members of the Soils Survey of the U. S. Department of Agriculture discovered sillimanite in the schist in Spartanburg and Greenville counties, South Carolina. Smith[24] in 1943 briefly described these occurrences in the Engineering and Mining Journal. Recently, W. H. Hudson[11], of the U. S. Bureau of Mines, Gainesville, Georgia office, has sampled and studied several of the deposits. The South Carolina deposits resemble the ones described in this report from Hart, Elbert, and Madison counties, Georgia.

Sillimanite in Georgia

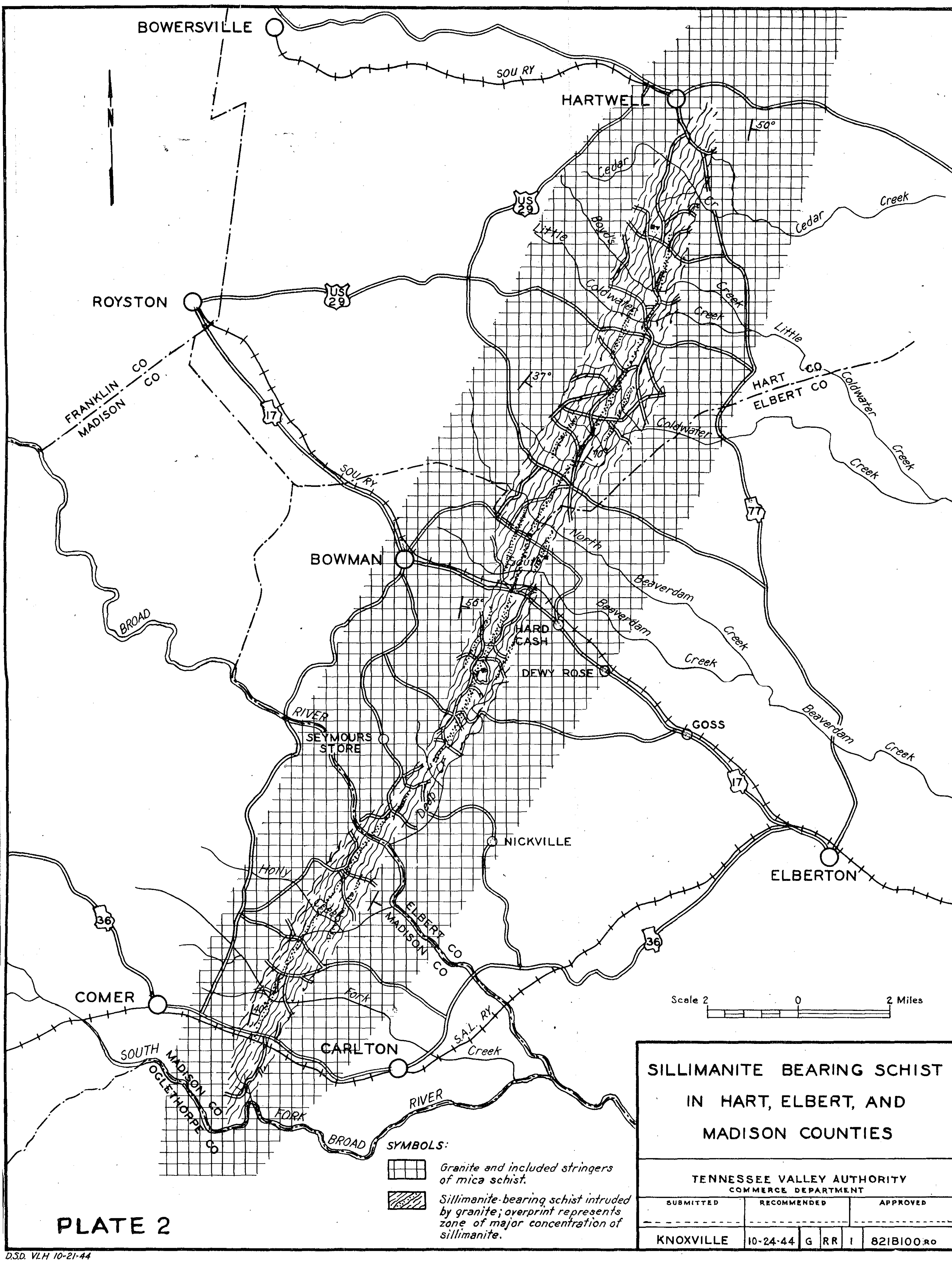
In the summer of 1943 Dr. R. J. Smith submitted a sample of sillimanite from Davy Mountain, North Carolina, on the Georgia State line, to the Georgia Department of Mines, Mining and Geology. The sample was discovered by Ab Ford of Warne, North Carolina, who pointed out the location of the deposit to Furcron. A joint project between the Georgia Department of Mines, Mining and Geology and the Mineral Section of the Regional Products Research Division of Tennessee Valley Authority was organized, and Furcron and Teague traced this zone into Georgia to the vicinity of Hunter Knob, Towns County. Dr. James L. Calver and W. T. McDaniel, Jr., Geologists for the Tennessee Valley Authority traced the belt northeastward into North Carolina to the vicinity of Tusquitee. Several of these localities were prospected; samples were collected and a sillimanite concentrate was prepared from the samples by the Chemical Engineering Department of the Tennessee Valley Authority.

In September, 1944 the extensive area of schists and gneisses east of Atlanta designated as "Carolina gneiss" on the State Geological map [9] were investigated by Furcron and Teague. Small local occurrences of sillimanite are quite common in the area, but a belt of schist rich in sillimanite was discovered and described from Hart, Elbert, and Madison counties. Several of the better localities from this belt were prospected by the writers, and the samples were sent to the U. S. Bureau of Mines where a sillimanite concentrate was prepared at the Southern Experiment Station, Tuscaloosa, Alabama.

CLASSIFICATION OF SILLIMANITE DEPOSITS IN GEORGIA

Several types of sillimanite deposits have been noted during the course of this study. The deposits exhibit parallel features in classification with kyanite.

(1) Sillimanite crystals and bundles of crystals disseminated in schist which have been intruded and recrystallized by granite and pegmatite. This type of deposit seems to offer most promise for the commercial production of sillimanite. Deposits in South Carolina, the belt described in this report from Hart, Elbert, and Madison counties, Georgia, and the deposits near Mt. Monadnock, New Hampshire, belong in this class. (2) Stringers and lenses of fibrolite, or fibrous sillimanite and quartz in schist associated with intrusive pegmatite and granite; the stringers may or may not be crosscutting; also they may be sufficiently abundant to form zones of sillimanite schist which generally parallel pegmatite intrusions.


BOWERSVILLE
SOU RY
HARTWELL
N
50°
Cedar
Creek
Cedar
US 29
Little
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Cr
Coldwater
Creek
Creek
ROYSTON
US 29
Little
HART CO
ELBERT CO
Coldwater
FRANKLIN CO
MADISON CO
37°
17
Coldwater
Creek
Creek
40°
SOU RY
North
77
BOWMAN
South
Beaverdam
56°
Beaverdam
Creek
HARD CASH
BROAD
DEWY ROSE
Creek
RIVER
SEYMOURS STORE
GOSS
Beaverdam
Creek
Deep
17
NICKVILLE
ELBERTON
Holly
Creek
ELBERT CO
MADISON CO
36
36
COMER
Fork
40°
S.A.L. RY
SOUTH
CARLTON
Creek
MADISON CO
OGLETHORPE CO
FORK
RIVER
BROAD
Scale 2 0 2 Miles
SYMBOLS:
Granite and included stringers of mica schist.
Sillimanite-bearing schist intruded by granite; overprint represents zone of major concentration of sillimanite.
SILLIMANITE BEARING SCHIST IN HART, ELBERT, AND MADISON COUNTIES
TENNESSEE VALLEY AUTHORITY
COMMERCE DEPARTMENT
SUBMITTED
RECOMMENDED
APPROVED
KNOXVILLE
10-24-44
G
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D.S.D. V.L.H. 10-21-44

PLATE 2

The deposits described from the Davy Mountain-Brasstown Church area, and from many other isolated occurrences are of this type. These deposits are generally small; fine grinding is necessary in order to obtain a concentrate. (3) Nodules and segregations of massive sillimanite in schist; local occurrences noted from Davy Mountain and Hart County. (4) Button and flattened "pebble-like" masses of sillimanite (fibrolite) and quartz in schist. This peculiar type, "pseudo-conglomeratic" in character, is described from the region of Amicalola River in the second part of this report. (5) Sillimanite replacing kyanite. Examples of this type may be found in the Davy Mountain-Brasstown Church belt. Prindle [21] figures an occurrence of this type from Hyatt Mill Creek, 3 miles south of Hayesville, North Carolina.

SILLIMANITE IN HART, ELBERT, AND MADISON COUNTIES

Numerous occurrences of sillimanite of the stringer or vein type and of the disseminated type are found in these counties. These deposits resemble those found in South Carolina; some of them appear to be better than the ones thus far described from that state. A zone of sillimanite schist of probable commercial value is described from these counties (Plates 1 and 2).

Location

Most of the deposits discovered recently in these counties occur in a belt of schist extending south and southwest of Hartwell (Plate 2). The belt has been traced for a distance of about 23 miles, extending from Hartwell southwestward through Hart County, through Elbert County, just east and south of Bowman, and through the eastern end of Madison County between Comer and Carlton to the Oglethorpe County line. The exact boundaries of the belt are obscured by weathering; its width is variable. Between Hartwell and Bowman the belt is approximately two miles wide, and the sillimanite-bearing schist zone near its southwestern terminus is about a mile wide. This belt, illustrated in Plate 2, contains numerous zones of granite which are difficult to separate from the schist because rock outcrops are scarce and the soil covering is deep. The richest zone (Plate 2) is found near the middle of the belt between Little Coldwater Creek, south of Hartwell and Holly Creek just southwest of the Elbert-Madison County line. Isolated occurrences of sillimanite-bearing schist have been found beyond the border of this belt, and detailed prospecting in the future may discover other belts with a high sillimanite content in this same general area.

Accessibility

The Seaboard Airline Railway crosses the southern end of the belt between Comer and Carlton, and a branch of the Southern Railway crosses the middle portion of the belt between Bowman and Elberton. This branch crosses the best part of the belt near Harper; it connects with the main line of the Southern at Toccoa and with the main line of the Seaboard at Elberton. Hartwell, at the northern terminus of the belt, is connected with the Southern Railway by the Hartwell Branch. Thus the best deposits are close to or only a few miles from rail transportation.

The belt is also completely accessible to truck and automobile by paved highways and a net-work of secondary roads. State Highway Number 36 crosses the southern end of the belt between Comer and Carlton. Georgia Highway Number 17, another paved highway, parallels the Southern Railroad between Bowman and Elberton, connecting with U. S. Number 29 at Royston. A graded soil road parallels the eastern side of the belt between Elberton and Hartwell. Short stretches of secondary roads render all sections of the belt readily accessible to railways and improved roads. The large amount of quartz from weathered granite imparts a sandy character to most of the soil roads so that they are passable generally at all times.

Topography, Streams, and Climate

The area under discussion lies in the eastern part of the Central Upland in Georgia. Most of the belt is in the northern part of the Washington Plateau which slopes from about 800 feet above sea level near Hartwell to about 500 feet at the southern junction with the Coastal Plain. The upland surface is flat, and slopes to the streams are gentle.

The entire region is drained by tributaries of Savannah River. The two principal streams are Broad River which crosses the belt at the Elbert-Madison County line, and the South Fork of Broad River at the southwestern terminus of the belt between Madison and Oglethorpe counties. These two streams unite east of Carlton to flow into Savannah River. Numerous streams, with sufficient water for concentrating plants, cross the belt between Broad River and Hartwell among which North Beaverdam, Robinson, Coldwater, Little Coldwater, Boyds, and Cedar Creeks may be mentioned. Thus all of the deposits are within short distances of ample water supply.

This section of Georgia is a medium to thickly settled agricultural district where cotton is the principal crop. There is ample labor in normal times for agricultural and mining developments.

Climatic conditions encourage mining operations at all seasons of the year. The normal mean temperature of January for the Hartwell area over a period of 43 years is 44.0° F.

Description of Sillimanite

In the principal sillimanite zone the mineral occurs as prismatic, compact bundles of crystals disseminated in the schist. The percentage and size of the crystals and bundles are subject to variation in the different layers of schist. The enclosing rock is biotite-quartz-muscovite schist more or less garnetiferous. Tourmaline and magnetite are accessory minerals. Tourmaline is abundant locally where crystals cover surfaces of joints which cross-cut the sillimanite or occur locally in the schist with sillimanite. The sillimanite crystals are generally arranged in the plane of schistosity. In most beds they tend to be oriented with the strike of the beds. In some of the beds the crystals are small, even microscopic in size; in others the bundles of crystals are as much as two inches long, and one-quarter of an inch in diameter; the bundles are more or less rectangular in cross section. Flattened crystal growths develop in the plane of schistosity forming crystal fans on weathered surfaces with a general angle of 30° from the focus of growth. Sillimanite may be distinguished from kyanite in

Figure 1. Sillimanite crystals in biotite gneiss, headwaters of Coldwater Creek, about 6 miles southwest of Hartwell, Hart County.

the field by the simple test of hardness. The mineral is clear, gray to blue-gray in hand specimen, but transparent beneath the binocular microscope; luster is silky to sub-adamantine. All the crystalline bundles exhibit a prominent cross-fracture. In some zones the sillimanite is intergrown with biotite.

Geology of Deposits

Rock exposures are generally poor in this area. The flat upland surface is covered by a thick mantle of lateritic soil. The underlying granites, as a rule, produce a light gray sandy soil, whereas the schist, if not extensively granitized, produces a red clay loam. Quartz fragments, and occasionally loose boulders of granite occur in the soil. For the most part the presence of the underlying sillimanite-bearing schist is determined by numerous bundles of iron-stained sillimanite present at the surface. In the richer parts of the belt the sillimanite schist crops out in ledges, especially near streams.

The dominant rocks at the surface in this part of the state are granites and schists. The schists are intensely folded and highly metamorphosed. Strikes are northeast-southwest; dips are prevailingly steep and to the southeast, but in most places are difficult or impossible to determine at the surface. The schists are intimately intruded by granite so that zones of schist and granite alternate. In many places the schists are more or less assimilated by granite, thus all stages between a true mica schist and a true migmatite exist. The schists appear to represent the remnants of meta-sedimentary biotite schist, muscovite schist and gneiss which occur in this area. The original sediments in this part of the state consisted of fine-grained arkosic beds alternating with clay or shale beds. The arkosic beds are generally altered to a biotite gneiss or graywacke, and the clay beds to mica schist. In this section graywacke beds are not common, and the clay beds which were originally highly aluminous, are now altered to sillimanite-mica schist. Without doubt the original sediment has been altered by large scale folding and regional metamorphism, but these rocks, representing the folded roots of the old sedimentary formation, are more altered and more coarsely recrystallized than are the rocks to the west which have also suffered the same regional effects. The recrystallization of the muscovite, biotite, and sillimanite are believed to be due to the intimate relation of the rock here to the intrusive granite, pegmatitic granite, and pegmatite. The present granites and pegmatites associated with the sillimanite deposits are generally thought to have been intruded at the close of Paleozoic time. Diabase dikes of Triassic age crosscut all of the other rocks, but have no bearing upon the problems under consideration.

Size of Deposits

The belt of sillimanite-bearing schist as illustrated by Plate 2 contains numerous sillimanite-bearing zones which are separated by bands of granite. In most cases, the thick soil precludes accurate estimates of thickness and extent of the ore bodies until they have been prospected. The schist occurrences represent tightly compressed synclines and bands of schist included in the granite. The best zone as indicated by Plate 2 extends continuously along the strike for about 15 miles. Poor exposures make estimates of thickness difficult, but this zone contains bands at least 600 feet thick in some localities where exposures permit better observation. The deposit could be mined by open cut methods and observable factors indicate that it could be mined to any economically feasible depth. Most of the suitable mining sites are well above water level.

The per cent of sillimanite present in the schist varies in direction normal to the strike, the proportion being different with the individual bands or original sedimentary beds. Also in some bands locally, sillimanite has been sericitized. The per cent of sillimanite by weight will vary from a few per cent up to 50 per cent. Careful sampling across the strike should precede mining operations. Assuming an average sillimanite content of 15 per cent mined over a length of one-half of a mile to a width of 100 feet and to a depth of 50 feet, a rough estimate of the total amount of refined sillimanite obtained would be 1,780,000 short tons. Upon the same basis a rough estimate for the entire sillimanite belt of the richer zone described above would amount to over 54,000,000 tons of refined material.

Description of Deposits

The following is a brief, running-description of occurrences of sillimanite discovered by the writers September, 1944 in the belt illustrated by Plate 2. This is necessarily a brief statement because there has been no prospecting and outcrops are generally concealed. The best outcrops of massive ore and the best mill sites are found at localities where prominent streams cross the zones of sillimanite schist. The belt as mapped consists of several zones of sillimanite schist separated by zones of barren schist and granite. The following statements refer mostly to the richest zone.

The belt crosses Georgia Highway 36 between Comer and Carlton in the southern part of Madison County, 2.4 miles east of the highway junctions in Comer. This appears to be about the southern terminus of the belt. South of this locality, in Oglethorpe County granite appears at the surface. South of highway 36 and the South Branch of Broad River, the sillimanite crystals are altered to sericite.

The belt mentioned above is continuous northeastward through Madison County, and is exposed at a road junction three miles N 74° E of the center of Comer. Loose blocks of good ore are numerous in the soil. On the north side of Holly Creek and mill 1.5 miles west of Broad River the zone crosses the road. The sillimanite-bearing schist strikes N 27° E here. Two other zones separated by granite occur in the belt northwest of this locality.

Very good outcrops are found in Elbert County along the road on the north side of Deep Creek about one mile S 62° E of Smith's School. The beds strike N 30° E. The sillimanite-bearing zone is about one quarter mile wide at this locality. The principal zone is intruded by granite and several other bands of the schist are included in granite on its northwest side.

Excellent exposures are found along a road and near a small stream three miles S 45° E of Bowman. Ledges of sillimanite-biotite schist with a near vertical dip strike N 18° E. The sillimanite content of the exposed beds is rather high. Just west of the sillimanite belt at a road intersection two miles S 26° E of Bowman fragments of massive muscovite rock with numerous crystals of blue cleavable corundum are found beside the road in a cultivated field.

The northernmost exposures in Elbert County may be seen along the road a mile northeast of Harper. The rocks, largely unexposed, strike N 40° E. The soil of the flat upland surface contains, as in many other localities, numerous iron-stained fragments of sillimanite schist.

In Hart County along both sides of the road just northeast of North Beaverdam Creek, brown oxidized pebbles of sillimanite and mica schist are abundant in the fields. Loose blocks and fragments of rock with a high content of sillimanite are found in the fields northeast of the occurrence mentioned above, and south of Robinson Creek. Ledges of the same rock may be seen near a road junction just north of Robinson Creek. The rocks strike N 34° E and weathered ledges and fragments of sillimanite schist indicate a thickness for this zone of 600 or more feet. Along the roads north and northeast of this locality fragments of sillimanite schist are abundant in the soil. Ledges rich in sillimanite, crop out in the county road between two road junctions a mile northeast of the locality described immediately above.

Northeast of the Charles R. Dove property two wide belts of sillimanite schist may be traced by float, and the occurrence of massive ledges. Where these zones cross Coldwater Creek on the property of Dr. Joe Jenkins fresh exposures of massive sillimanite schist occur. Several good quarry sites occur here near the stream.

On the east side of Coldwater Creek about three-quarters of a mile east of the above locality, mica schist, striking N 24° E contains isolated segregations or lenses of light gray sillimanite, and sillimanite and quartz up to several pounds in weight.

Rock fragments high in sillimanite occur in the belt south of Little Coldwater Creek in the general vicinity of Bio Church. A stone wall on the east side of the churchyard is composed of these rocks. No good sillimanite deposits have been found to date northeast of this locality, although numerous fragments of sillimanite schist may be seen along the roads just southeast of Hartwell. If this belt enters South

Carolina it appears not to be continuous north and east of Hartwell where the rocks are coarse granitized muscovite schist. Local occurrences of schist containing some sillimanite are generally scattered over the entire county. Undoubtedly, similar local occurrences can be found in adjoining counties. Small stringers and lenses of fibrous sillimanite also are of common occurrence in this part of Georgia.

An example of the fibrous, stringer, or vein type of sillimanite occurring associated with pegmatites may be seen in the highway cuts of U. S. 29 between Hartwell and Anderson, South Carolina, just west of the Savannah River bridge on the Georgia side. Numerous sillimanite-bearing schist zones occur here interlayered with barren graywacke or quartzite beds. The beds are much contorted, exhibit reverse folding, and are intruded by granite and pegmatite. This occurrence resembles that of the Brasstown Church-Davy Mountain belt described at another place in this report.

THE REFRACTORY PROPERTIES OF GEORGIA SILLIMANITE*

(Preliminary report)

Samples of sillimanite schist from Pelzer, South Carolina, and from 3.5 miles N.E. of Bowman, Hart County, Georgia, were beneficiated at the Southern Experiment Station of the Bureau of Mines, Tuscaloosa, Alabama. These schists were similar in nature, the principal impurities being quartz, muscovite, and biotite; much of the sillimanite was prismatic in form. The methods employed in beneficiation are summarized as follows:

Each sample was ground to 28-mesh with acceptable liberation of sillimanite, and concentrated by gravity tabling and flotation. The Georgia material contained about 15 per cent sillimanite, and of this 80 per cent was easily recoverable in concentrates that required magnetic separation of iron-bearing minerals to leave a final concentrate containing only

* Refractories section, Electrotechnical Laboratory: T. N. McVay, Senior Engineer; Dorothy R. Pate, Junior Engineer; Dan Allen, Physical Science Aide.
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0.9 per cent ferric oxide and 93.3 per cent sillimanite, calculated from the alumina assay. The Georgia material contained coarser grains of sillimanite, a few being as large as 14-mesh. The concentrates from both sources contained little material finer than 200-mesh, thus very little sillimanite passed into the slime tailing. A more complete report on the beneficiation of sillimanite is being written by the Mineral Dressing Section of the Southern Experiment Station, and will soon be released for publication.

The sillimanite rock was received from South Carolina in 1944, and about 500 pounds of minus 28-mesh concentrates were shipped to the Electrotechnical Laboratory, Norris, Tennessee, for testing. At a later date a smaller sample of Georgia sillimanite was beneficiated, and 17 pounds of concentrates were shipped to Norris. As shown in table 1 the chemical analyses of the South Carolina and Georgia concentrates are similar. However, the Georgia sillimanite sample contained about 2 per cent more silica than the South Carolina mineral. This silica content can be reduced by further concentration. The two samples came from different portions of the same geologic formation and therefore are expected to show the usual natural variations.

TABLE 1.—*Chemical analyses of nonmagnetic sillimanite concentrates, per cent* *

	Georgia	South Carolina
SiO_2	39.69	37.59
Al_2O_3	57.95	59.75
TiO_2	.20	.24
Fe_2O_3	.99	1.20
Total	98.83	98.78
Calculated sillimanite	92.3	95.2

* Analyses by R. H. Stacy, Southern Experiment Station and P. G. Cotter, Electrotechnical Laboratory.

Table 2 gives the screen analyses of representative samples of the two sillimanites. The Georgia concentrate was the coarser. However, both are finer than 28-mesh, and it is unlikely that a coarser grain can be obtained from either schist unless quality is sacrificed. The quartz is interlocked with the sillimanite in the schist, thus it is necessary to grind to minus 28-mesh to free the sillimanite.

TABLE 2.—*Screen analyses of nonmagnetic Georgia and South Carolina sillimanite, per cent*

Mesh No. coarser than—	Georgia	South Carolina
28	0.2	0.1
35	11.0	2.3
48	30.5	12.0
65	50.2	32.3
100	71.1	58.1
150	84.7	76.5
200	94.2	89.8
Total	100.0	100.0

Small specimens 2x1x1 inches in size were pressed at 7,500 psi. and then fired 4 hours at 1500° C. The results of the firing tests are given in table 3.

TABLE 3.—*Properties of specimens made from sillimanite samples after firing 4 hours at 1500° C.*

Specimen number	Porosity, per cent	Volume shrinkage, per cent	Color
Georgia sillimanite			
1	30.6	2.1	Mottled light brown
2	30.0	1.6	Mottled light brown
3	30.0	1.1	Mottled light brown
Average	30.2	1.6	Mottled light brown
South Carolina sillimanite			
1	31.2	2.0	Mottled light brown
2	30.6	1.0	Mottled light brown
3	30.6	2.0	Mottled light brown
Average	30.8	1.7	Mottled light brown

The data given above show close similarity between the two sillimanite concentrates.

Time did not permit completion of the refractory tests on the Georgia sillimanite. However, since it is believed that the material adjacent to the common boundary line of the two States is very similar, a brief review of data based upon samples from South Carolina will be given.

The preparation of the standard-size test brick was the same as that reported in the section on Georgia kyanite. The brick compositions contained 90 per cent sillimanite concentrates and 10 per cent Florida plastic kaolin, with 2 per cent organic bond for dry strength. After pressing at 7500 psi. and drying, they were fired to either 1475° or 1600° C. (2912° F.). All brick had good structures. Brick made from the acid-washed sillimanite were nearly white except for scattered brown specks, while all of the others were a strongly mottled light brown color. The linear shrinkage of the brick ranged from 0 to 0.2 per cent, which shows that there was practically no linear change in firing to 1600° C. The brick were reheated 5 hours at 1600° C. and met both the reheat specifications of the American Society for Testing Materials and those of the United States Navy for superduty refractories.

The results of the high-temperature load tests indicated that the sillimanite brick have excellent load-carrying capacity at high temperatures, and in the alumina-silica class are probably exceeded only by electrocast corundum-mullite.

Inversion of the sillimanite to mullite proceeded rapidly at 1650° C. with a volume expansion of about 6.7 per cent and a linear expansion of about 1.2 per cent. This change may occur at a lower temperature with increase in time of heating. The temperature of inversion is above that usually encountered in refractory service. The small expansion at such high temperatures suggests good rigidity and resistance where most refractories are beginning to show softening and weakening under load.

The brown appearance of fired sillimanite brick is due to biotite and limonite on the surface of the grains. The color can be improved by acid leaching. If sillimanite is ground to pass 200-mesh it is much whiter when fired.

Possible Uses.—Sillimanite should find use in superduty refractories, but unlike kyanite it is not necessary to calcine it before use. Brick made from acid-washed sillimanite may find service in glasshouse refractories. It should be possible to develop high-temperature cements containing sillimanite. Finely ground sillimanite should prove a valuable ingredient in electrical insulators and chemical porcelain.

Additional work.—The preliminary results indicated above will be confirmed by further tests. The spalling characteristics will be studied.

The brick that have been made in the past have been fired at 1475° and 1600° C. It is likely that the firing temperature may be decreased without detriment to the excellent temperature resistance shown. This would appear logical because of the constancy of volume of the sillimanite.

Refractories made from acid-washed sillimanite are being tested in glass tanks under service conditions. Further studies are necessary to complete the removal of iron-containing compounds for all white products. An investigation of the use of sillimanite in all types of special ceramics and refractories, including electrical and chemical porcelains, is planned.

SILLIMANITE IN TOWNS COUNTY, GEORGIA, AND CLAY COUNTY, NORTH CAROLINA

Location of Deposits

The sillimanite deposits described under this heading occur in a zone of mica schist in Towns County, Georgia, extending northeastward into Clay County, North Carolina (Plate 1). Thus far in this zone, sillimanite has been found as far southwestward into Georgia as Winchester Creek Valley; thence, it has been traced northeastward continuously across Hunter Knob through the Brasstown Church section where it crosses the State line a mile east of Georgia Highway No. 66. In North Carolina, it has been traced to the vicinity of Tusquitee, in Clay County.

Topography, Water Resources, and Accessibility

This area occurs in the western part of the Piedmont Plateau east of the Blue Ridge Province. Three local types of topography are significant—hills and low mountain ridges which rise above the plateau surface with Davy Mountain, elevation 2951 feet, the most prominent; a plateau surface with an average elevation of 1900 feet characterized by gently rolling topography; flood plain flats with an average elevation of 1700 feet are developed along the major streams, and are shown best in the vicinity of Warne Post Office, North Carolina.

In general, rock exposures are fairly abundant in the area. The major streams, Brasstown Creek and tributaries, and Crawford Creek, are persistent, and generally flow northwestward across the prevailing strike of the rock.

Hayesville, North Carolina, on the Tennessee and North Carolina Railroad, is five to seven miles northeast of the deposits, and is connected with them by Georgia Highway No. 66, and U. S. Highway No. 64. Other towns near and connected with the sillimanite area by paved roads are Blairsville, Georgia, 12 miles southwest of the deposits, and Murphy, North Carolina, 15 miles west of the area. Ordinary labor is easy to obtain in this district, which supports a rural population of more than average density.

General Geology and Petrology

The rocks of the area involved are of igneous and meta-sedimentary origin. These rocks occur in the western portion of the great central belt of crystalline rocks which crop out in Georgia. All of the rocks here described are mapped as belonging to the "Carolina gneiss" on the Georgia Geologic map of 1939[9]. This complex of rocks has been regarded by all investigators as of pre-Cambrian age, but appears to belong to the younger pre-Cambrian series.

Several facies of meta-sedimentary gneiss occur in this district. The most abundant rock types are layers of pepper-and-salt colored biotite gneiss or graywacke interlayed with bands of coarse biotite schist. The gneiss bands are massive, thus more resistant to weathering. Examined with a hand lens they reveal a medium fine-grained, even-granular mass of quartz and feldspar, with considerable biotite. In thin section the rock consists mostly of plagioclase, orthoclase, and quartz. A considerable amount of fine biotite and some muscovite occur arranged to produce schistosity. Specimens examined contain numerous grains of yellow epidote which also are generally oriented in the plane of schistosity. Bands of biotite schist interlayed with the type described above are very schistose. The biotite is coarsely crystallized, and in the few fresh exposures found and examined, these zones are thoroughly saturated with pegmatite usually in the form of very small "eyes" and stringers. In weathered outcrops the rock has a golden brown color where there has been some oxidation of iron and addition of water through weathering. The biotite schist zones are less resistant to weathering.

A third facies of the altered sediments is quartz mucovite schist of variable composition. More or less graphite in very fine flakes almost always occurs. A much higher graphite content is noticed south of this district where the zones are wider, thicker, and more prominent. This is especially noticeable in the vicinity of Nottely Dam. In the latter locality these schist bands generally contain more or less kyanite which may occur as individual crystals in the schist or as small masses of flat interlocking crystals. The kyanite shows more or less alteration to muscovite. The sillimanite deposits discussed in this report are found in an unusual zone of the quartz muscovite schist. In this zone sillimanite appears to have been formed in place of kyanite, although local deposits of kyanite occur closely associated with the sillimanite belt.

Dikes and stringers of pegmatite are common where they intrude all facies of the gneiss. Generally the stringers occur parallel with schistosity or with the bedding of the gneiss, but cross-cutting dikes and apophyses are of frequent occurrence. Locally, mica is absent. In many localities the dikes contain small sheets of muscovite, but much of the mica is of the "A" variety; many of the books are bent, and in all of the occurrences examined the mica is too small to have commercial value as sheet mica. Some of the pegmatite dikes and stringers which intrude and saturate the biotite schist facies of the gneiss contains numerous small books of sheet biotite.

Description of Ore

The ore consists of sillimanite locally associated with kyanite (see classification of deposits). It is found in zones of muscovite quartz schist, which occurs interlayed with beds of biotite gneiss or graywacke. Granite pegmatite stringers and lenses are common in the ore and associated rocks. The sillimanite occurs as lenses and as more or less continuous thin zones in the schist. The ore is locally almost all sillimanite, but usually contains more or less quartz and muscovite as an impurity. Float ore, from weathered ledges, or where the rock is thoroughly decayed in place is iron stained. Locally the ore shows more or less alteration to muscovite or damourite. The ore occurs as zones in the belt of muscovite-quartz schist. At Brasstown Church at least four zones occur which contain more or less ore. A brief description of sillimanite deposits in Towns County, Georgia and Davy Mountain, North Carolina is given below.

Distribution of Deposits

The following is a brief description of the sillimanite deposits extending northeastward from Winchester Creek, Towns County, Georgia, to Davy Mountain, North Carolina. The general strike of the zones described in the following pages is N 40° E with a dip generally steep and to the southeast. This zone continues northeastward from Davy Mountain and is described in other pages of the report.

In the valley of Winchester Creek some loose sillimanite and crystals of blue-bladed kyanite are found in the road near an abandoned homesite. These crystals are derived from a zone of muscovite quartz schist about 45 feet wide. Northeastward from this locality, and on the northeast side of Hunter Knob, a 100-foot zone of muscovite quartz sillimanite schist containing a small amount of graphite is exposed in the country road. Sillimanite is distributed throughout the zone where it occurs locally in lenses up to 4 inches thick.

Continuing northeastward along a line of approximately N 40° E fragments of float sillimanite schist are present more or less continuously to the vicinity of Brasstown Creek. Along the abandoned highway southwest of Brasstown Church, a zone of silimanite-bearing schist 30 to 35 feet thick crops out. The sillimanite ore occurs as narrow bands and lenses in the schist. Prospecting of this locality reveals that a large percentage of the sillimanite here has been altered to sericite.

In the yard of Brasstown Church, and in the highway cuts northeast of Brasstown Church, numerous zones of sillimanite-bearing schist interlayered with barren biotite gneiss or graywacke occur. A mica pegmatite is exposed associated with the sillimanite schist zone in the highway cut. The width of the zone at this locality is from 15 to 35 feet. A selected sample of the sillimanite schist taken from the highway cut contained approximately 4 per cent sillimanite.

Northeast of the above locality, and along the North Carolina-Georgia state line in the vicinity of Davy Mountain, numerous exposures of the sillimanite schist zone occur. More accessible portions of the deposit in Davy Mountain extend from the gap near the state line northeastward to Kimball Gap. The sillimanite was first discovered at this locality.

The thickness of the sillimanite-bearing zones cannot be determined in this area from the outcrops. Ledges 6 to 8 feet in thickness are exposed, and it is reasonable to assume from the float and distribution of the ledges that the total thickness is approximately the same as at Brasstown Church.

The ore from all the localities described above consists of lenses and stringers of sillimanite in a quartz muscovite schist containing more or less graphite. The richer samples of ore may be practically all sillimanite, but they generally contain more or less quartz and muscovite. The ore-bearing schist is rather thoroughly intruded and saturated by pegmatite.

This belt is continuous into Clay County, North Carolina, where it was studied and sampled by James L. Calver and William T. McDaniel, Jr., of the Tennessee Valley Authority. They traced the zone from the vicinity of Davy Mountain northeastward to the junction of Cold Branch with Tusquitee Creek. The following summary of this work was submitted by Calver:

"The portions of the schist which carry sillimanite form five more or less parallel zones. For a distance of 10 miles northeast of the Georgia-North Carolina line the schist belt contains parallel zones in which the mineral sillimanite appears to be concentrated. The belt of schist varies in width from less than 0.2 to 0.5 of a mile. Beyond that portion of the schist which has been mapped, the sillimanite content diminished and gives way to kyanite. Channel samples taken across the schist at various localities contained up to 9.9 per cent sillimanite across a 20 foot zone, and chip samples from small prospect pits indicate that some portions of the schist carry as much as 20 per cent sillimanite. Inasmuch as all the sillimanite is more or less intergrown with quartz and mica, very fine grinding would be necessary to release the mineral for concentration and recovery."

Sampling and Concentration

Several samples of the sillimanite-bearing schist were collected in Towns County, Georgia, and Clay County, North Carolina, at various localities along the strike of the belt. Sillimanite content of the samples was determined by the Department of Chemical Engineering, Tennessee Valley Authority, Muscle Shoals, Alabama.

In most cases an effort was made to sample the better grade of material. The samples collected showed a variable sillimanite content ranging in general from 2.5 to 7 per cent sillimanite for channel samples, and from 8.5 to 21.5 per cent sillimanite for selected chip samples.

A 24-pound sample of sillimanite flotation concentrate, representing about 40 per cent recovery of the total sillimanite of the ore, was prepared from two of the larger samples. Fine grinding of the ore was necessary in order to free the sillimanite from the enclosing minerals. A mineralogical analysis of the concentrate showed the following minerals: Approximately 90% sillimanite, 5% muscovite, 3% quartz, 2% graphite, 0.24% Fe_2O_3.

Origin of Deposits

The sillimanite deposits here described correspond to type two of the classification. Both kyanite and sillimanite in Towns County, Georgia, and Clay County, North Carolina, occur in zones of muscovite-graphite schist which were probably highly aluminous, representing an old meta-sedimentary facies of the pre-Cambrian gneiss. Southwest of the sillimanite-bearing schist similar zones, as in the vicinity of Nottely Reservoir, contain kyanite, but in that area pegmatites are few or absent. Where sillimanite occurs, pegmatites are abundant, and in many places have thoroughly saturated the schist. The sillimanite observed occurs always in schist, and the evidence suggests that it has been formed in the more highly aluminous layers during the intrusion of the pegmatite. Some specimens from Davy Mountain and other localities still retain the structure and outward physical appearance of kyanite, thus it appears that locally, at least, kyanite produced by hydrothermal alteration of the schist was converted to sillimanite through the action of later, hotter pegmatite solutions. Since the writers believe that the sillimanite was produced during the period of pegmatite injection, the deposits were formed probably at the close of the Paleozoic Era. It is believed, also, that the pegmatites are older than the final period of shearing and mylonitization.

PART II

MASSIVE KYANITE DEPOSITS AND ASSOCIATED ROCKS

INTRODUCTION

This part of the report discusses the massive kyanite deposits and their associated rocks in parts of Cherokee, Pickens, Gilmer, and Dawson counties. The rock units, as given by previous writers, have been redefined and reclassified. The first part of this section is devoted to a description of the rocks with special reference to marble, sericite, chlorite, and other economic features, and to a reinterpretation of the structure and stratigraphy of this part of the State. The later pages are devoted to the description, classification, and possible uses of the massive kyanite ore.

TOPOGRAPHY AND DRAINAGE

The central and southern part of this area lies in the Piedmont Upland, and the northern part in the Appalachian Mountain Province. Mount Oglethorpe (elevation 3290 feet), six miles east of Jasper, represents the southern terminus of the Blue Ridge Mountains. That portion of the area underlain by Amicalola gneiss has an average elevation of 1500 feet and belongs to the Dahlonega Plateau. Its surface is rolling, hilly, and low mountains occur which stand several hundred feet above the Plateau surface. The belts represented by the shear zones are less resistant, thus in general are worn down to lower elevation; over these sheared rocks the Atlanta Plateau extends, with an average elevation of 1150 feet.

The major stream courses of the area are determined to a considerable extent by structural features. Etowah River generally follows the shear zone southwest of Dawsonville, and Long Swamp Creek and other streams follow the shear zone west of the Marble Hill overthrust line to connect with Etowah River southeast and southwest of Ball Ground. The northwestern part of the area is drained by Talking Rock Creek, a tributary of Coosawattee River which flows into Etowah River at Rome, Georgia. All of the area is drained by tributaries of Etowah River, the larger of which are Amicalola River and Long Swamp Creek.

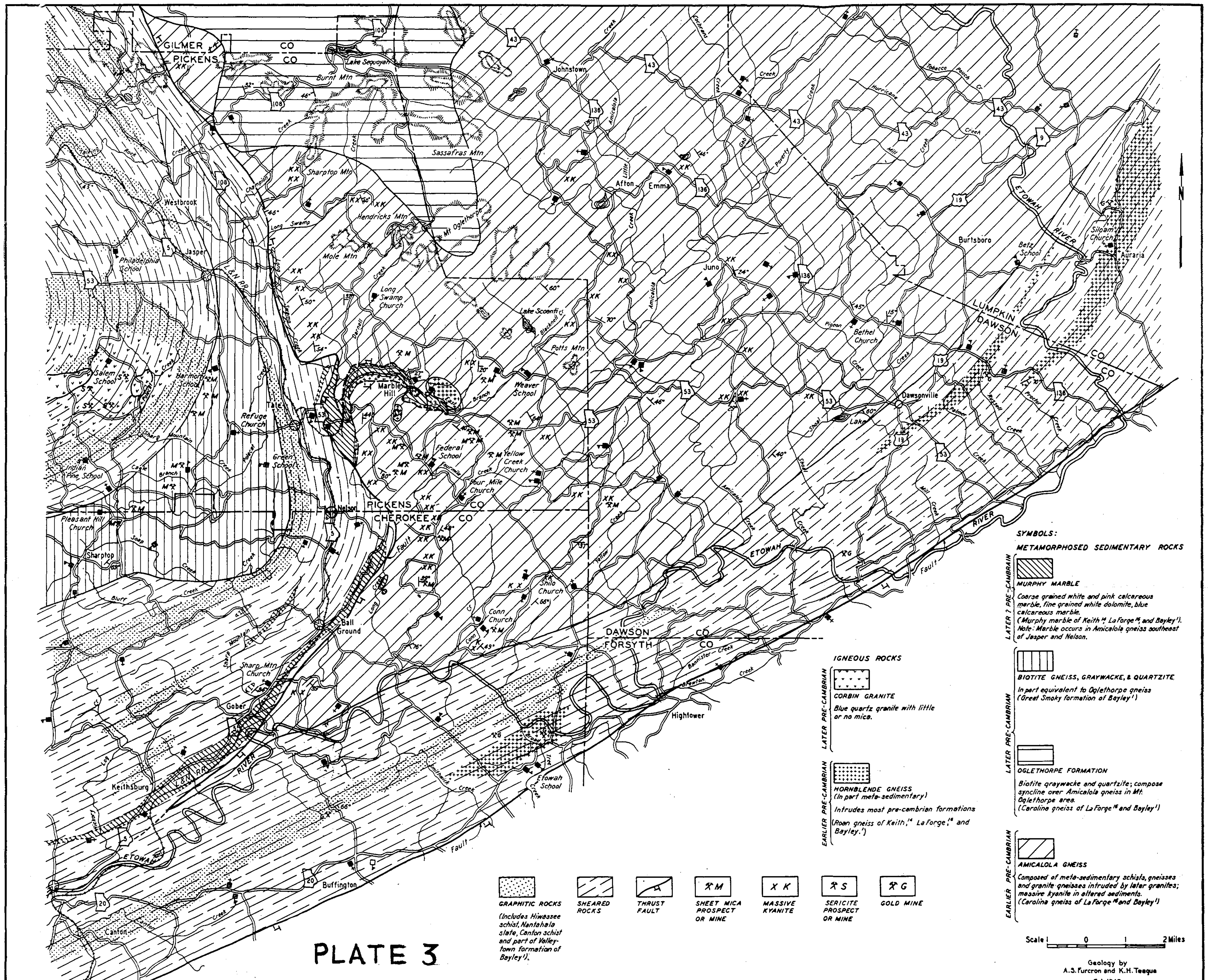

PLATE 3

GEOLOGIC MAP OF THE SOUTHERN END OF THE BLUE RIDGE MOUNTAINS IN GEORGIA

EARLIER PRE-CAMBRIAN ROCKS

Amicalola Gneiss

This formation is the facies of a great pre-Cambrian complex of igneous and meta-sedimentary rocks which consists of granite gneiss, pink granite and hornblende gneiss, and highly metamorphosed sedimentary rocks. In this area, where the gneisses contains deposits of massive kyanite, they are largely meta-sedimentary, but northeastward in Dawson and Lumpkin counties, granite gneiss composes an important part of the complex. The rocks here described were mapped by Bayley[1] as "Carolina gneiss," but because that term covers rocks of many types, and rocks of different geologic age, it is not retained in this report. The term "Amicalola gneiss" is here used to define that part of the pre-Cambrian basal complex of this area which contains much altered sedimentary rock and which is characterized by deposits of massive kyanite. Other subdivisions of this older gneiss are possible in other parts of the State.

Distribution

This gneiss is mapped in parts of Cherokee, Pickens, Gilmer, Dawson, and Lumpkin counties where the kyanite-bearing facies covers an approximate area of 150 square miles (Plate 3). The kyanite gneiss lies between Tate and Dawsonville so that a line connecting those two towns divides the area into about equal parts. It is covered on the north by overlying beds of Oglethorpe formation. The northernmost beds where small buttons of kyanite appear to have developed more or less parallel with the original bedding in the rocks may be seen at the marble monument on the top of Mt. Oglethorpe. On the south and southeast, the formation is terminated by the Dawsonville shear zone. Likewise its western boundary is marked by the Marble Hill overthrust. This gneiss or its equivalent, may re-appear in other places in the Blue Ridge region of Georgia, North Carolina, or Virginia.

Geology and Petrology

The rock consists of layers of gneiss and schist intensely folded, highly metamorphosed, and injected by granite, peg-

Figure 2. Oglethorpe formation, on Burnt Mountain, Pickens County, containing typical ellipsoidal granite intrusions.

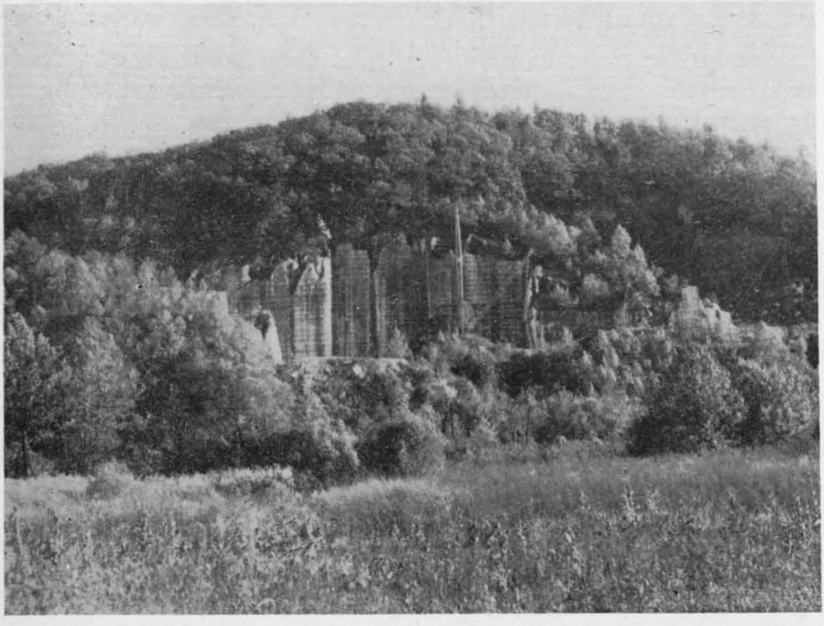

Figure 3. New York quarry, Marble Hill, Georgia, viewed from the north. The marble dips to the south under Amicalola gneiss.

matites, quartz veins and stringers, and occasionally by hornblende gneiss. Biotite gneiss layers commonly referred to as graywacke, represent the more massive layers, thin to several feet in thickness. They are composed of quartz, brown biotite, muscovite, potash feldspar, plagioclase, and garnet. The rocks are light gray to dark gray in color depending upon the percentage of feldspar and biotite.

Thin sections were examined of a schistose facies of the gneiss one and one-half miles due south of Ball Ground which contains small oval, lenticular aggregates of kyanite. The most notable feature of this rock is the presence of ragged porphyroblasts of brown biotite and garnet which contain inclusions of other minerals. These crystals have grown against the grain of the rock, and occur in it near the edge of the overthrust block. Quartz, muscovite shreds, plagioclase, and small kyanite aggregates compose the remaining portions of the rock. Interlayed with the gneiss beds are garnetiferous mica schists and gneisses. The dominant mica is biotite, but muscovite is present and locally abundant. Kyanite and staurolite are noted locally. Conglomerates are very rare if they occur at all.

The lumps of massive kyanite are found in the more schistose portions and never in the graywackes. Certain layers in the schist referred to by Bayley[1] as "fish scale" gneisses contain the lumps of massive kyanite. This facies has been invaded by pegmatite and granite juices causing the growth of numerous small "buttons" of kyanite, muscovite, and combinations of the two. In general, where small "buttons" of kyanite are exceedingly abundant, large lumps are rare. The little kyanite "buttons," except for size, resemble the large lumps of massive kyanite. However, they may contain mica, and because of their small size are more heavily iron stained. They serve as a good index to the presence of the kyanite-bearing rocks. They are very abundant in the soils locally, as for example, in the vicinity of Dug Road, east of Marble Hill and also south of Mackey School, six miles east of Ball Ground. The prevalence of kyanite and mica "buttons" suggested the name for old Mica Post Office in Cherokee County.

In addition to the kyanite-quartz-muscovite "buttons," flattened and pebble-like masses of quartz and sillimanite occur in coarse biotite gniess near the northern terminus of the kyanite-bearing gneiss. This variety of gneiss is best developed in the vicinity of Old Johnstown along the road west from Johnstown to Connahaynee Lodge and in the vicinity of Secunti Lake, three or four miles north of Holcomb. These "pebbles" form beds which superficially resemble a metamorphosed conglomerate. Good exposures of the zone may be seen on the gravel road about a quarter of a mile west of Old Johnstown. The first road cuts west of Amicalola Creek reveal several "pebble" zones. One of the zones is over 30 feet thick, and "pebbles" up to two inches in diameter compose from 30 to 40 per cent of the entire rock. A thin section of one of these pebbles consists of masses of fine sillimanite fibers composing about 25 per cent of the section. These fibrous masses weave about enclosed quartz grains. These rocks, and the rocks in this vicinity are cut by narrow vein-like stringers of sillimanite which are associated with pegmatites and quartz veins.

Dips and strikes in this formation are extremely variable; reverse folds are abundant. In many places over the area dips are gentle. Generally speaking, in the western portion of the area, strikes tend to parallel the western edge of the overthrust block and dips are eastward. Near the southern border, the strikes of the rock tend to be parallel to the Dawsonville shear zone and dips are southward. Apparently the old pre-Cambrian structures have not been obliterated here at the southern end of the Blue Ridge by later Paleozoic movement.

LATER PRE-CAMBRIAN ROCKS

In the northern part of this area (Plate 3) metamorphic rocks of later age overlie the Amicalola gneiss. These rocks and associated formations above them which occur north of the area under discussion are believed to be of later pre-Cambrian age. They unconformably overlie Amicalola gneiss, and are much more metamorphosed than are known Paleozoic rocks in Georgia. In a recent article the Stoses[26] have classified this great rock series as Ocoee in age. No fossils have been found in the Ocoee series, and in Georgia these rocks are separated from known Paleozoic rocks by the Cartersville overthrust. Thus it is difficult to demonstrate their geologic age in this State, but their degree of metamorphism and their relation to the old complex suggest a late pre-Cambrian age for them. Their highly metamorphic character makes them difficult, locally, to separate from the Amicalola gneiss; for this reason some earlier writers have confused them with the old gneiss complex. The Stoses[26] report that in the Roan Mountain, North Carolina and Greenville, Tennessee quadrangles, Lower Cambrian rocks appear to overlie this series in stratigraphic sequence.

Oglethorpe Formation

Thick massive layers of biotite gneiss overlie Amicalola gneiss in the northern part of the area. The petrology and structure of these rocks may be studied along the road between Jasper and Connahaynee Lodge and Mt. Oglethorpe, where a large syncline in these rocks forms the top and western sides of the mountain. The rock in this section is a medium-to-thin bedded, fine-grained, even-granular biotite gneiss, graywacke, and arkose. Flagstone quarries are opened in it in some places.

Only the lower part of the formation is exposed in the Mt. Oglethorpe area. This portion of the formation is well exposed north of this locality in a road quarry on the Ellijay-Dawsonville Highway about five miles southeast of Ellijay. In this quarry, as well as in the Mt. Oglethorpe section, the rock is characterized by peculiar oval-shaped granite-like segregations or intrusions. The formation is terminated westward about two miles east of Ellijay by a coarse blue quartz conglomerate, above which there is an extensive formation of dark graphitic slates and quartzites. This latter formation, comprising the principle graphitic zone in the Ocoee Series, has been named the Nantahala slate in this area by previous writers. The blue quartz conglomerate zone mentioned above has not been separately mapped in Georgia. That part of the Series from the base of the Nantahala formation downward to the old complex was mapped by LaForge as the Great Smoky formation of Lower Cambrian age. In this area it is convenient to regard the Oglethorpe formation as

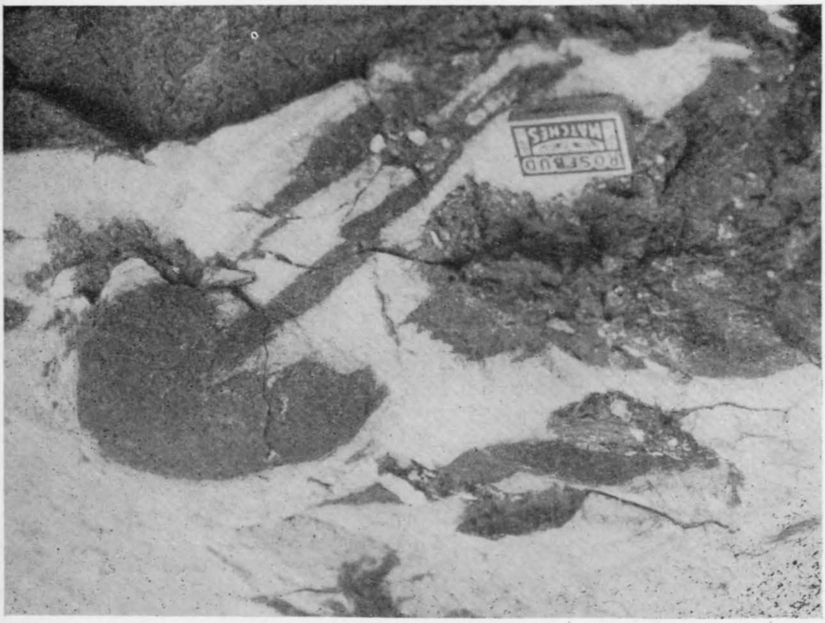

Figure 4. Hornblende gneiss stringers and lenses in marble, quarry on east bank of Long Swamp Creek, 1 mile northeast of Tate Post Office, Pickens, County.

that part of the Series between Amicalola gneiss and the blue quartz conglomerate beds. Formations in this Series are subject to considerable change in physical character and thickness locally, thus are difficult to trace over an extensive area. Later field work may show that it is expedient to map all of the rocks of the Series below the main graphitic zone (Nantahala slate) as a single formation. Care should be exercised in the field to prevent confusion between the rocks here regarded as Nantahala slate and numerous other graphitic zones of less thickness and extent.

Biotite Gneiss, Graywacke, and Quartzite West of Nelson

A large area of unsheared rocks, consisting mostly of graywacke, quartzite, and some blue quartz conglomerate occur west of the shear zone which follows the Marble Hill overthrust. Most of these rocks consist of garnetiferous biotite graywacke interlayed with beds of garnet-mica schist. Beds of garnetiferous graphitic schist are common. Fresh outcrops seldom occur in the area, but where they are found, the rocks lithologically resemble those of the later pre-Cambrian series. No massive kyanite has been discovered, but local areas of kyanite-bearing schist, and staurolite schist occur; also there are some deposits of the vein-type of kyanite. One of the principal mica pegmatite areas of this part of the State occurs in these rocks. It is probable that these rocks correspond in part to the Oglethorpe formation.

Murphy Marble

The Murphy marble was named by Keith* from the town of Murphy, Cherokee County, North Carolina. The rock is not all marble; extensive bodies of hornblende schist occur with it, which are believed to have been derived from portions of the original calcareous sediments. Also in Georgia, and especially further north in North Carolina, bodies of talc and tremolite are common in the marble.

The marble has been described in several reports [1, 14, 16]. It consists of coarse to finely-crystalline white, gray, blue, and locally pink marble. Analyses indicate that the total com-

*Keith, Arthur, Murphy folio, U.S.G.S., unpublished

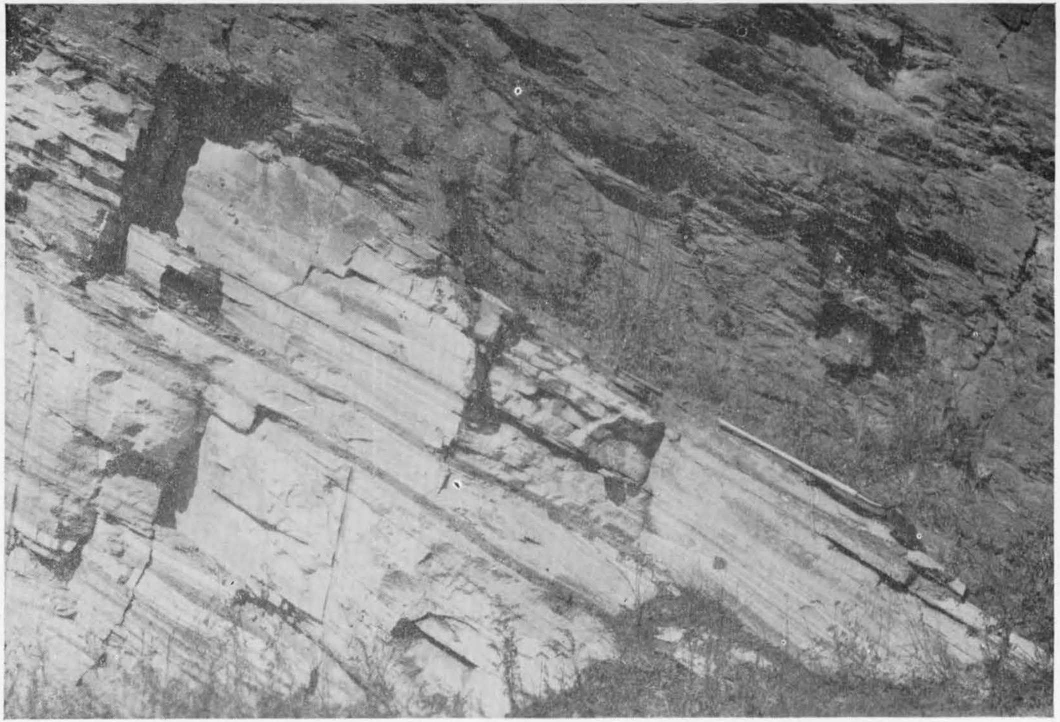

Figure 5. Contact between Murphy marble (beneath) and biotite garnet gneiss (above), on road near Long Swamp Creek about 2¼ miles southeast of Jasper, Pickens County.

bined carbonates generally range between 60 and 95 per cent. The white, fine-grained varieties are dolomitic with a MgO content as high as 20 per cent. The best marble of the belt thus far discovered for building and monumental purposes, occurs east of Tate near Long Swamp Creek. In this area the marble is massive and large blocks of marble free of joints and cleavage planes, and uniform in composition are obtained.

An examination of the geological map (Plate 3) indicates that the hornblende gneiss is closely associated with the marble. Field evidence supports the view that the hornblende and actinolite associated with marble are derived from a calcareous facies of the formation, although all of these rocks have been mapped previously as of igneous origin. Brown biotite and calcite characteristic of the marble also occur in this hornblende schist. Bands and lenses of hornblende and hornblende and biotite occur locally in the marble, and hornblende schist and marble are interlayered opposite the Cherokee quarry. Other bodies of hornblende rock in the old gneisses are generally regarded as of igneous origin since those bodies contain an appreciable amount of garnet and feldspar.

Stratigraphic Position and Geologic Age

The term "Murphy Marble" is retained in this report although it would have been better if the formation had been named from the vicinity of Tate or Marble Hill where practically all of the commercial dimension stone is obtained, and where the deposits are best developed. The writers disagree with Keith's interpretation of the stratigraphic position and geologic age of the marble.[14] Keith recognized in the Murphy marble belt above the pre-Cambrian gneisses a series of formations of Lower Cambrian age, the youngest of which are the Murphy marble and Nottely quartzite. The formation beneath the Murphy marble, he called the Valleytown. This rock type from Canton, Georgia to the Little Tennessee River in North Carolina consists of sheared rocks and green phyllites of dubious origin. Various writers have found it necessary from place to place to include almost every rock type of the area in the Valleytown formation in order to follow the original stratigraphic sequence of Keith. For these and other reasons given later there may be no Valleytown formation as described.

Reasons for assuming a Cambrian age for rocks of the Murphy marble belt have not been expressed clearly by Keith[14], LaForge [16], and Bayley[1]. These rocks are not connected with Paleozoic sediments of established age, and no fossils have been found in them. The problem is further complicated by the occurrence of the marble with sheared rocks associated with established overthrusting.

In the Marble Hill area the marble underlies the Amicalola gneiss. However, this gneiss is thrust over the marble at this locality. About one-half mile northeast of Tate Post Office on the road to Federal School, Amicalola gneiss over the marble is sheared. On the north side of the valley at Marble Hill immediately opposite the New York quarry, Amicalola gneiss containing sheared kyanite buttons appears to dip directly under the marble.

A body of marble surrounded by hornblende gneiss is enclosed in Amicalola gneiss at the old Amicalola quarry about one mile south of Marble Hill. The marble body is intruded by mica pegmatites. Two other similar occurrences of marble are found two miles north of Ball Ground. The writers have not found any physical indications of thrusting associated with these latter occurrences, thus the marble either occurs in the Amicalola gneiss or in some manner reached its present position through flowage. Elsewhere throughout the area of the geologic map (Plate 3) marble occurs generally with sheared pre-Cambrian rocks.

At Whitestone, on the Gilmer-Pickens County line, a block of slightly graphitic late pre-Cambrian quartzite and slate is thrust over the eastern side of the marble. The rocks beneath the marble are poorly exposed, but where observed they are sheared.

In the old marble quarry at Marble, North Carolina the marble seems to have an anticlinal structure, and its northwestern limb dips northwestward under late pre-Cambrian graywackes which are garnetiferous, contain unaltered biotite porphyroblasts, and exhibit a double cleavage.

One of the best exposures of marble is at Hewitts, Macon

Figure 6. "Stretched pebbles" produced by shearing of a quartz vein, 1 mile north of Burroughs Cross Roads, Cherokee County.

Figure 7. Pseudo-conglomerate composed of sillimanite-quartz lenses in Amicalola gneiss, 1 mile west of Old Johnstown on State Highway 108, Dawson County.

County, North Carolina, near the northern end of the belt. At this place all of the rocks dip southeast. Marble is exposed at the bottom and on both sides of the gorge of Nantahala River which at this place is over a thousand feet deep. The marble bed is completely enclosed by late pre-Cambrian rocks. On the east side of the gorge marble is well exposed along the highway where it dips under quartzite, graywacke, and biotite-muscovite-quartz slate which is slightly graphitic. On the west side of the valley at the quarry it is underlain by green slaty phyllite which may be sheared. Below the phyllite and to the west are extensive deposits of late pre-Cambrian quartzites and slates. Most geologists will agree that the marble and immediate-enclosing rocks at this locality have been affected by thrust faulting, but even if faulting is present both above and below the marble it is difficult to explain its present position unless it is assumed that the marble occurs in this late pre-Cambrian series.

The observations given above suggest that the marble is closely associated with Amicalola gneiss near the southern end of the Blue Ridge, but in the middle and northern portions of the belt it is associated with rocks classified as of later pre-Cambrian age. At present it is possible to suggest a number of hypotheses concerning its age and stratigraphic position, but the burden of evidence indicates that it is pre-Cambrian. Much more detailed work should be done in this area, for not only are the relations of marble to gneisses obscure, but the origin of the green phyllites is open to question; also the relation of Nottely quartzite to marble is not established. For these reasons the stratigraphic position of the Murphy marble as expressed in the legend (Plate 3) is regarded as tentative.

The marble is an intensely metamorphosed rock—certainly much more highly altered than Lower Cambrian limestones and dolomites in the Great Valley. Crystals and bands of biotite are numerous in it; tremolite is a characteristic mineral, occurring as individual crystals or as masses of tremolite and marble. Locally, the marble has been altered to hornblende and actinolite.

IGNEOUS ROCKS

Detailed descriptions of these rocks may be found in other reports[1, 8, 16, 29]. A very brief description of the igneous rocks in the area studied is given below.

Hornblende Gneiss. Hornblende gneisses and amphibolites occur locally throughout the area. They are found in the Amicalola gneiss along Georgia Highway No. 53 east of the Dawson-Pickens county line. Elsewhere in the area of Amicalola gneiss they are found where they may be associated with pink granite. These rocks are especially prevalent in the vicinity of the marble in the Marble Hill area where some of the hornblende appears to have been derived from marble.

Sheared hornblende gneisses are common in the Dawsonville shear zone where they are associated with the gold deposits. Occasional bodies of hornblende gneiss are found in the later pre-Cambrian sediments. These rocks are regarded as of pre-Cambrian age.

Corbin Granite. Small areas of this granite occur in the vicinity of Salem Church in Pickens County. Most of the rock is sheared and locally reduced to a sericite mylonite. The term "Salem Church granite" of Bayley[1] is not retained here because the granite is similar in all respects to the Corbin granite described by Hayes east of the Cartersville overthrust. This rock is a blue quartz, microcline granite which contains practically no mica. It is similar to certain other pre-Cambrian granites which are found in the Blue Ridge to the north.[7]

Mica Pegmatites. A considerable amount of sheet mica has been produced from the Amicalola gneiss area south of Marble Hill. Another mica mining area is found in late pre-Cambrian graywacke and quartzite west of Nelson. These pegmatites are believed to be of late Paleozoic age. They are not found except in a highly sheared condition in the principal shear zones of the area. The location of the more important mines and prospects may be found upon the geologic map (Plate 3). A complete discussion of these and other mica-bearing pegmatites in the State has been published by the writers.[8]

Diabase Dikes. Intrusive dikes of coarse to fine grained diabase are found in the crystalline rocks of the eastern part of North America from Nova Scotia to Alabama. These rocks are fresh and undeformed, and correspond mineralogically to known intrusions of Triassic trapp in Nova Scotia, New York, New Jersey, Virginia, etc. The principal minerals of the diabase are usually augite and labradorite, but some of the dikes contain olivine. Bayley[1] has described several dikes from this area. At the A. W. Amphlett mica mine, five miles east of Ball Ground, a diabase dike cuts the mica pegmatite.

SHEARED ROCKS

In this area several extensive zones of sheared rocks occur. These shear zones involve practically all of the rock types previously described in this report. In many localities the rocks have been so deformed that the original formation cannot be recognized because a secondary platy cleavage has completely obliterated the original structure. Where these processes are most intense, the rocks approach in physical character the appearance of mylonites. Certain retrogressive mineral changes may take place in the rock. In this area feldspar alters to sericite, hornblende and biotite to chlorite, and tremolite to talc. All stages between unaltered granites, gneisses, and graywackes to completely sheared-out rocks may be observed.

An extensive zone of deformed rocks here referred to as the Dawsonville shear zone lies north of an overthrust which extends from Canton northeastward through Dawsonville. West of the Marble Hill overthrust there is another extensive shear zone which follows the Murphy marble belt and unites with the Dawsonville belt in the vicinity of Canton. West of this belt other sheared rocks are present as indicated upon the geologic map (Plate 3). In the unsheared gneisses and schist, dips are frequently gentle or rolling and strikes are variable, whereas in the shear zones, dips are uniformly to the east and southeast, and strikes are more regular. Thus a sudden change to a uniform southeastern dip is characteristic of the sheared rocks.

Tate Shear Zone

This belt includes rocks previously mapped by Keith[14], La-

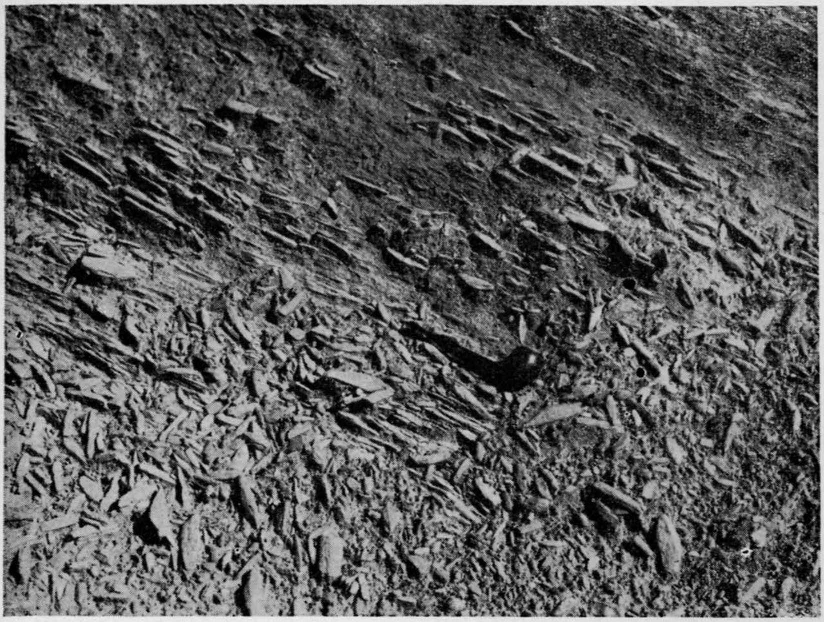

Figure 8. Sheared quartz vein producing "stretched pebbles" or pseudo-conglomerate, 1 mile north of Burroughs Cross Roads, Cherokee County.

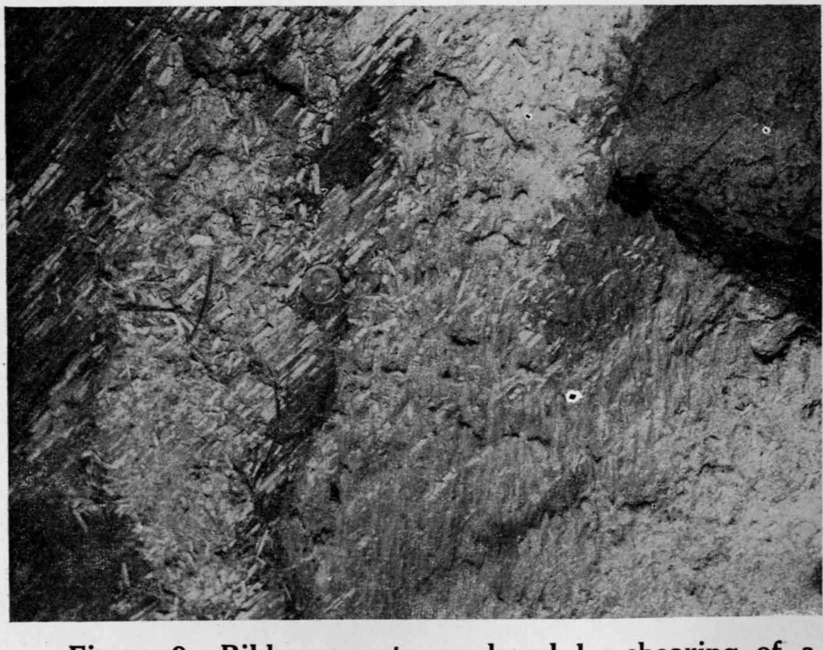

Figure 9. Ribbon quartz produced by shearing of a quartz vein, 3 miles northeast of Ellijay, Gilmer County.

Forge[16], and Bayley[1] as belonging to the Nantahala, Valleytown, and Murphy marble formations of Lower Cambrian age. However, the various facies of the sheared rocks appear to represent sheared equivalents of various types of pre-Cambrian rocks. Most of the previous writers have identified extensive effects of shearing, but seem not to have attached sufficient significance to the observation. Bayley[1] (page 67) notes that the Valleytown formation of the Tate quadrangle consists mainly of graywacke beds and thinly layered silverly garnetiferous mica schist. He calls special attention to the amount of shearing in the rocks, stating "where very greatly sheared, the Valleytown mica schists are thin plates of crowded mica flakes that readily break down and furnish a soil that consists almost exclusively of mica flakes and a few garnets."

The Tate shear zone is about six miles in width at its junction with the Dawsonville shear zone near Canton. The belt becomes narrower to the north and varies considerably in width of outcrop. For example, at Ellijay the belt is less than one mile wide. It is not easy to understand if these rocks were normal formations how, with their great thickness in the vicinity of Canton and Ball Ground, they could all pass through such a narrow space at Ellijay.

In a region where all the massive rocks are intruded by granites and late Paleozoic pegmatite, the absence of intrusions in these zones is striking and significant. The writers believe that the igneous intrusions in the shear zones have been completely sheared out so that their identity has been destroyed. Two miles southeast of Jasper, and about one-half of a mile west of the marble quarry on the road to Long Swamp Creek Church, a sheared mica pegmatite is exposed in the road. The feldspar is altered to sericite, and the quartz is sheared into thin plates and rolled parallel to the schistosity. The small mica books have been rounded and also oriented.

Granites have been extensively sheared in the area around Salem Church in Pickens County. All stages from unaltered granite to a mylonite consisting entirely of sericite, with more or less quartz, occur; the pure apple-green layers of sericite-mylonite have been mined for years in this district. Hornblende gneisses are altered to chlorite schists. These rocks resemble basic rocks in the northwest Highlands of Scotland where they are sheared into chlorite schists on the soles of thrust blocks. Sheared-out chloritized rocks of this type are abundant, and well exposed where they are mined north of Canton.

Although recrystallization prevails over simple cataclastic structure in the less resistant rocks, massive quartzose and arkose beds, and quartz veins, tend to be sheared out without much chemical alteration, at least toward the western and northwestern side of the shear zones where the non-resistant rocks have lost their original structure. Where the effects of differential movement have become less, extensive granulation and cataclastic structures are developed in the resistant rocks. The feldspars and quartz in the arkose beds are smeared out into long knotty strings. The most peculiar effects are noted in the quartz veins and occasionally in conglomerates. Where the veins are thin, the quartz is smeared out into long parallel ribbons. In many places, the veins have been sheared out into elongated pebble-like fragments described by McCallie as "stretched pebbles." These pseudo-conglomerates have not been noted in the intensely sheared rocks. They may be encountered along the roads wherever quartz veins were present before thrusting took place, to form a sort of zone between the sheared and unsheared rocks. Examples of such sheared-out quartz veins or pseudo-conglomerates may be seen on the road between the paved highway and Whitestone, on a dirt road just west of the paved highway 2.5 miles north of Ellijay, and along the roads one and one-half miles north of Burroughs Crossroads some eight miles north of Canton. Effects somewhat similar to this have been observed in sheared out granite in the vicinity of Salem Church where large quartz grains are involved.

Dawsonville Shear Zone

This belt has an average width of four or five miles in the region under discussion. East, south and southwest of Dawsonville, extensive granite intrusions appear in the overthrust block southeast of the shear zone. The rocks of this belt consist of the sheared equivalents of granite, graywacke, biotite schist, and hornblende gneiss now in the form of thinly plicated chlorite schist, muscovite-chlorite-quartz schist, etc. Many of the beds are garnetiferous. One facies described by Bayley[1] as "Canton schist" is a glistening, bluish gray, garnetiferous mica schist which contains a small amount of graphite. Chlorite schist derived from hornblende gneisses are especially well exposed south and southwest of Dahlonega. Quartz veins and stringers which post-date thrusting are common in this sheared belt. In fact, the prominent gold mines are located in this zone of sheared rocks. Near the western or northwestern side of the belt, quartz veins that preceded thrusting are sheared into pseudo-conglomerates which may be observed along the dirt roads south and southwest of Keithsburg. They have been produced also in the Amicalola gneiss by local shearing about two miles south of Ball Ground.

KYANITE DEPOSITS

The mineral kyanite is widespread in areas of crystalline rocks although the massive form described in this report has been recognized previously only from India.

Massive Kyanite in India

Kyanite rock from Lapsa Buru, India, was shipped before the war from Calcutta to England, the United States, Germany, Belgium, and Italy. Kyanite production began in India in 1924, and had totalled 33,000 tons by the end of 1933. Production has increased since that date so that 24,886 tons were exported from India in 1937. Over 96 per cent of the kyanite came from Lapsa Hill[3] in Kharsawan, where it was quarried by the India Copper Corporation, Ltd. Shipments of India kyanite have been curtailed recently partly by lack of shipping facilities and partly by threat of Japanese invasion. Although 14,285 short tons valued at $175,218 were imported from India in 1941, our imports dropped to 6,524 tons with a value of $93,743 in 1942. During 1941, the shipping rate on kyanite imported from Calcutta increased from $11.20 to $16.80 a short ton, and the price rose from $25.00 to over $30.00 a short ton. In 1942 the price of India kyanite was $54.00 a short ton.

At Lapsa Hill[3] segregations of massive kyanite occur in beds of kyanite-quartz rock which is associated with muscovite and hornblende schists. Corundum is a common mineral in the massive kyanite segregations. Dunn believes that these deposits are the metamorphic products of highly aluminous or bauxitic clays. He estimates a minimum of 234,000 tons of massive kyanite in the Lapsa Buru deposit at the western end of the belt, and about 38,000 tons for other deposits.

Kyanite in the United States

Extensive deposits of kyanite occur in the eastern part of the United States in the crystalline mica schists. These deposits consist of crystals of kyanite disseminated in mica schists and quartzites. They are mined extensively in Virginia at Baker Mountain in Prince Edward County, and by the Celo Mines Incorporated (now Mas-Celo Mines Incorporated) at Burnsville, North Carolina. At present the latter operation is inactive. Kyanite from the belt in South Carolina, Georgia, and Alabama is not mined at the present time.

Kyanite in Georgia

The most important mined deposits of kyanite in Georgia are found in a "U"-shaped belt which is about 30 miles long and from 100 feet to a quarter of a mile wide in Habersham and Rabun counties north of Clarkesville.[21, 25] This type of ore has been extensively worked by Philip S. Hoyt of the Southern Mining and Milling Company, Clarkesville, Georgia, and by the A. P. Green Fire Brick Company of Mexico, Missouri. Flat crystals of kyanite up to ½ inch in width are disseminated through the mica schist which also contains small amounts of graphite. Similar occurrences have been described in the Ellijay folio[16] and are common from other parts of the State. The amount of kyanite in the schist ranges from 1 to 15 per cent, with a general average of 6 to 8 per cent at places available for mining. Locally in the belt, kyanite crystals are abundant in the soils overlying the schist. Placer deposits have been worked near Clarkesville.

Veins and lenses of coarsely-bladed kyanite occur in mica schist, and locally are associated with quartz lenses. Deposits of this type are usually small veins, or smaller lenses and nodules that are quite resistant to weathering; thus dornicks and boulders of kyanite from such occurrences may be found locally in the break-down over the primary schist and gneiss. Very little kyanite of this type has been mined in the State, probably because the deposits are small and lack continuity. A kyanite deposit on Gumlog Mountain in Towns County was prospected in 1931 by the A. C. Spark Plug Company. Very little ore was shipped.

At Graves Mountain in Lincoln County, crystals and aggregates of kyanite replace quartzite. The types of kyanite mentioned above have been discussed in Prindle's[21] report by D. W. Johnson.

In December 1939, Mr. T. M. York submitted several specimens of massive kyanite from the property of A. J. Elkins of Dawson County to the Georgia Geological Survey. The writers later examined this property and discovered numerous occurrences of similar material in Dawson, Pickens, Cherokee, and Gilmer counties. As far as is known, this is the only occurrence of this massive type of kyanite discovered thus far outside of India.

PHYSICAL PROPERTIES OF KYANITE

Some of the more commonly used physical properties of kyanite are given below. Kyanite, like sillimanite, has the chemical composition of Al_2SiO_5; when heated above 1350° C. it is converted to a mixture of mullite and silica or silica glass. The variety of kyanite found disseminated in schists, and also the type of interlocking tabular blue-bladed crystals associated with quartz veins and pegmatites, have a unique hardness. The hardness parallel to the long direction of the blades is 4, whereas across the crystals it is 7. These varieties are blue to bluish-gray in color, generally with the deepest color arranged in streaks or bands. Specific gravity of the mineral varies from 3.5 to 3.7; luster is vitreous to pearly.

The massive kyanite described in this report is unique in that the individual crystals seldom exceed an eighth of an inch in length. Also the crystals are tightly interlocked to form dense, compact masses with little or no pore space. The varieties of kyanite described in the above paragraph, when calcined become friable, whereas the massive variety remains

Figure 10. Boulder of massive kyanite in place in mica schist, 2 miles east of Tate Post Office, Pickens, County.

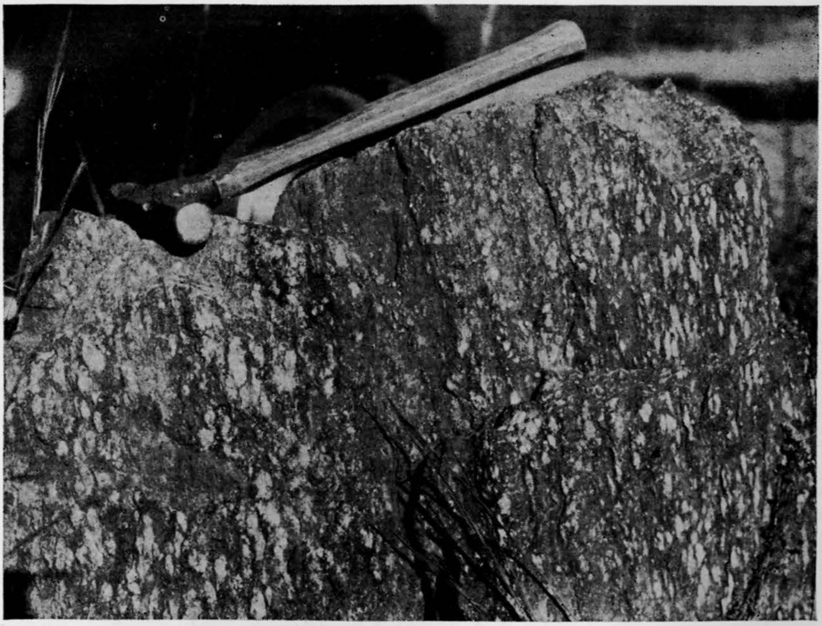

Figure 11. Button-like lenses of massive kyanite in mica schist, 1 ½ miles south of Holcomb, Pickens County.

dense and tough. The field test for hardness on massive kyanite is of little value.

Boulders of massive kyanite are bluish gray to grayish white in color; they may be confused in the field with massive barite, but are much tougher and more difficult to break than barite; also massive kyanite frequently contains corundum. The index of refraction of kyanite is from 1.712 to 1.728, thus distinguishing it from sillimanite with refractive indices of 1.659 to 1.680.

USES OF MASSIVE KYANITE

Massive kyanite from Georgia may be used in the same general type of refractories as the kyanite now imported from India. Refractories which use kyanite as the principal constituent are classified as high alumina refractories (approximately 60 per cent Al_2O_3).

Refractories made from calcined massive kyanite have a low coefficient of expansion under service conditions, comparatively high melting points, and resistance to loads at high temperatures, thermal shock, corrosive action of certain fluxing agencies, and furnace gases.

McVay and Wilson[17] give the more important uses of massive kyanite as "(1) linings for Ajax-Wyatt induction and indirect arc furnaces for melting and refining brass and bronze containing more than 75 per cent of copper and those metals that require higher temperatures than does yellow brass, (2) furnaces in which silica brick can be used for continuous service but spall during intermittent operation, (3) oil-burner ports and blocks, (4) super-structure for glass tanks exclusive of the silica-brick crowns, including the forehearth and mechanical feeder parts for forming machines and (5) heavily loaded kiln furniture for fast schedules in ceramic firing."

CLASSIFICATION OF KYANITE DEPOSITS IN GEORGIA

Several types of kyanite deposits have been noted during the course of this study. Although kyanite seems to be formed at a lower temperature than sillimanite, the two minerals show marked similarity in origin and mode of occurrence: (1) Kyanite crystals disseminated in mica schist or quartzite. The commercial deposits worked in Virginia, North Carolina, and Georgia are of this type. (2) Lenses, stringers, and vein-like masses of interlocking blue-bladed kyanite crystals associated with quartz veins and stringers, and pegmatites. This type was worked west of Ball Ground and by the A. C. Spark Plug Company on Gumlog Mountain, but, thus far, has not been mined on a commercial scale because the deposits are small and local in distribution. (3) Nodules or segregations of dense massive interlocking crystals of blue gray kyanite in biotite schist; sizes range from 800-pound boulders to small button-like masses; associated with pegmatites and intrusive quartz veins. This type of kyanite, similar to that imported from India, is described in this report. (4) Kyanite showing alteration to sillimanite.

DESCRIPTION OF MASSIVE KYANITE DEPOSITS

Size of Deposits

The ore occurs as lumps and boulders which are locally thickly scattered through the soil and sub-soil; the deposits range in size from a few scattered fragments to areas of several acres thickly covered with lumps of kyanite. None of the deposits have been prospected thus, although the commercial ore occurs in the soil and sub-soil, it is difficult to estimate the available tonnage which seems not to be large at any discovered locality.

Distribution of Deposits

Ore may be found practically anywhere in the area underlaid by the kyanite-bearing Amicalola gneiss. Local concentrations occur at many places. Localities where the writers have observed massive kyanite in the course of the work appear as crosses on Plate 3. Fragments of ore have not been observed in the first several hundred feet of gneiss over the marble. Also there are several extensive, essentially barren areas, in the kyanite formation, the largest of which occurs in the drainage area of Conn Creek in Cherokee County. One of the better series of deposits extends southeastward from Sharptop Mountain in Pickens County to a point about one mile north of the Marble Hill valley west of Marble Hill. The belt re-occurs immediately south of the valley, continuing

Figure 12. Large residual boulder of massive kyanite, near headwaters of Yellow Creek, Dawson County.

Figure 13. Residual boulders of massive kyanite, $2\frac{1}{2}$ miles east of Tate Post Office, Pickens County.

southeastward and southward to the vicinity of Cherry Grove School, Cherokee County. Further prospecting will undoubtedly discover new deposits.

Water-worn lumps of ore have been found in the gravels associated with some of the streams, thus suggesting the possibility of placer deposits. Observed localities of this type of material are along a tributary of Long Swamp Creek, southeast of Sharptop Mountain; along the headwaters of Talking Rock Creek, northwest of Sharptop Mountain, and along Price Creek near the Gilmer-Pickens county line.

Accessibility

This area, at the southern terminus of the Blue Ridge Mountains, is quite accessible, and well connected with the surrounding territory by auto-roads and railroads. The Louisville and Nashville Railway between Atlanta and Knoxville skirts the entire western side of the kyanite producing rocks. The principal railway stations along the line here are Canton, Ball Ground, Nelson, Tate, and Jasper. A spur track owned by the Georgia Marble Company, extends from the Tate station to Marble Hill.

A paved road, State Highway 5, parallels the course of the L. & N. Railway. At Tate this road connects with the paved highway to Dawsonville which passes through the central part of the area. At Dawsonville it connects with paved highways to Dahlonega, Gainesville, and Atlanta. The railroad and principal highways are connected to the surrounding countryside by a system of improved soil roads. Practically all of the deposits in the area are accessible by automobile or truck.

Description of Ore

The lumps and boulders of massive kyanite range from pea size to boulders that will weigh 800 pounds. Fifty-pound boulders are common, but larger sizes are generally unusual. In general, the boulders are rounded, of irregular shape, but more or less oval. Where observed in the schist matrix, the longer axis of the lens conforms to the schistosity. The lumps are gray, blue-gray to greenish-gray in color. They are easily mistaken for fragments of quartz, but are very tough and difficult to break with the hammer, and are of much greater weight. They are composed of numerous small interlocking crystals of kyanite which form a dense compact mass. They frequently contain small hexagonal crystals of blue corundum. Garnet and black tourmaline crystals often occur, especially against the outside of the lumps. Secondary quartz fills fractures in some lumps, but rarely the reverse condition is observed in which cracks in vein quartz fragments are filled with massive kyanite. The lumps are more or less iron-stained as would be expected from their residual origin. In thin section, the good ore is composed almost entirely of small interlocking kyanite crystals; a few small muscovite flakes are observed. Mica increases in quantity in the poorer grades of ore where it occurs as segregations and stringers which materially decrease strength and quality. Also, in some lumps the minute kyanite crystals show strong orientation in the longer direction of the mass. Lumps of this type are easier to break thus probably possess poorer firing qualities.

Prospecting Kyanite

Lumps and boulders of kyanite may occur almost anywhere within the area mapped as Amicalola gneiss (Plate 3) where they are associated with loose fragments of quartz. They may be discovered by driving along the country roads where lumps of kyanite can be observed in the road or at the surface in cultivated fields. Lumps appear to be the thickest in the soil near the surface, but they usually extend downward through the soil mantle to the weathered top of the bed rocks. The ore is a residual accumulation from weathering. Rarely is a lump of any size observed in the bed rock, thus test pits and trenches offer little opportunity for the discovery of ore in the rock layers beneath the soil mantle. Pits and trenches will determine the amount of ore in the soil zone; indeed, an examination of road cuts frequently serves as well, because the amount of residual kyanite left in the road and thrown out on the banks of the road serves as an index of the amount of kyanite present to the amount of soil removed. No mining problems are involved because the ore is to be picked up, thrown in a truck, and hauled away. If the position of the deposit is not marked or remembered, its location may be lost after the removal of the surface boulders.

The best area thus far discovered, forms a belt which extends along the east side of Long Swamp Creek. The deposits are not large but it is hoped that the publication of this report will lead to the discovery of others in this area or elsewhere. It is surprising that no other deposits of this kind have been reported, because it is entirely possible that they may occur in this belt of pre-Cambrian schists from Alabama to Pennsylvania.

Origin

These deposits closely resemble in occurrence and mineral composition those described by Dunn[3] between Salbanni and Ichadih in Barabhum, India. Dunn reports that the kyanite occurs in muscovite-quartz schist, locally replaced by quartz-tourmaline rock. Occurrences of crystals of blue corundum are found in the kyanite masses. The masses are of irregular shape and up to six feet in length in the schist.

The Georgia deposits appear to have been produced by the effects of pegmatites and hot quartz veins which have permeated the schist. The deposits frequently are associated with pegmatites, and always with more or less blocky quartz fragments of high temperature origin which may contain crystals of black tourmaline. Fragments of the ore vary in size from small buttons to boulders which will weigh as much as 800 pounds. The kyanite masses grew in certain aluminous layers replacing the schist. The presence of tourmaline in the massive ore, and its association with buttons composed of kyanite, quartz, muscovite, and tourmaline further evidence the high temperature origin of the deposits. Small crystals of gray to blue corundum are found in some of the fragments, but the massive kyanite deposits here described contain less corundum and slightly more silica than the India deposits.

THE REFRACTORY PROPERTIES OF GEORGIA MASSIVE KYANITE*

(Preliminary report)

After a small sample of the Georgia material previously discussed was identified as massive kyanite, two shipments were made to the Federal Bureau of Mines, Electrotechnical Laboratory at Norris, Tennessee. The first contained about 260 pounds and the second about 800 pounds of soil-stained, brown and gray lumps ranging from 2 or 3 inches in diameter to those weighing over 50 pounds. The unusual characteristics that distinguished these dornicks from the usual surface residuals were a high bulk specific gravity and tough resistance to impact and crushing. Some muscovite and garnet were present, but most of the material was high-grade kyanite, with a little corundum. One sawed lump contained corundum inclusions as large as ½ inch in diameter.

Preliminary firing of small lump samples. Six 1- x 2-inch specimens were taken from different lumps of massive Georgia kyanite, cleaned and fired at 1300° C., then progressively refired at 1400°, 1500°, 1600°, and 1700° C. The first two treatments were made in an electrically heated Globar furnace in an oxidizing atmosphere, the third was made in an oil-fired kiln and the 1700° firing was made in a graphite-resistor furnace which operated under strongly reducing conditions. In each case the maximum temperature was maintained for 4 hours except at 1700°, where the time was only 2 hours. Figure 14 shows the curves which represent the maximum and minimum volume (vol.) and apparent porosity (A.P.) changes and weight losses (wt. 1.).

Clay, diaspore, bauxite, and many other common refractory minerals shrink when heated to high temperatures, but kyanite and quartz expand. Expansion eliminates the manufac-

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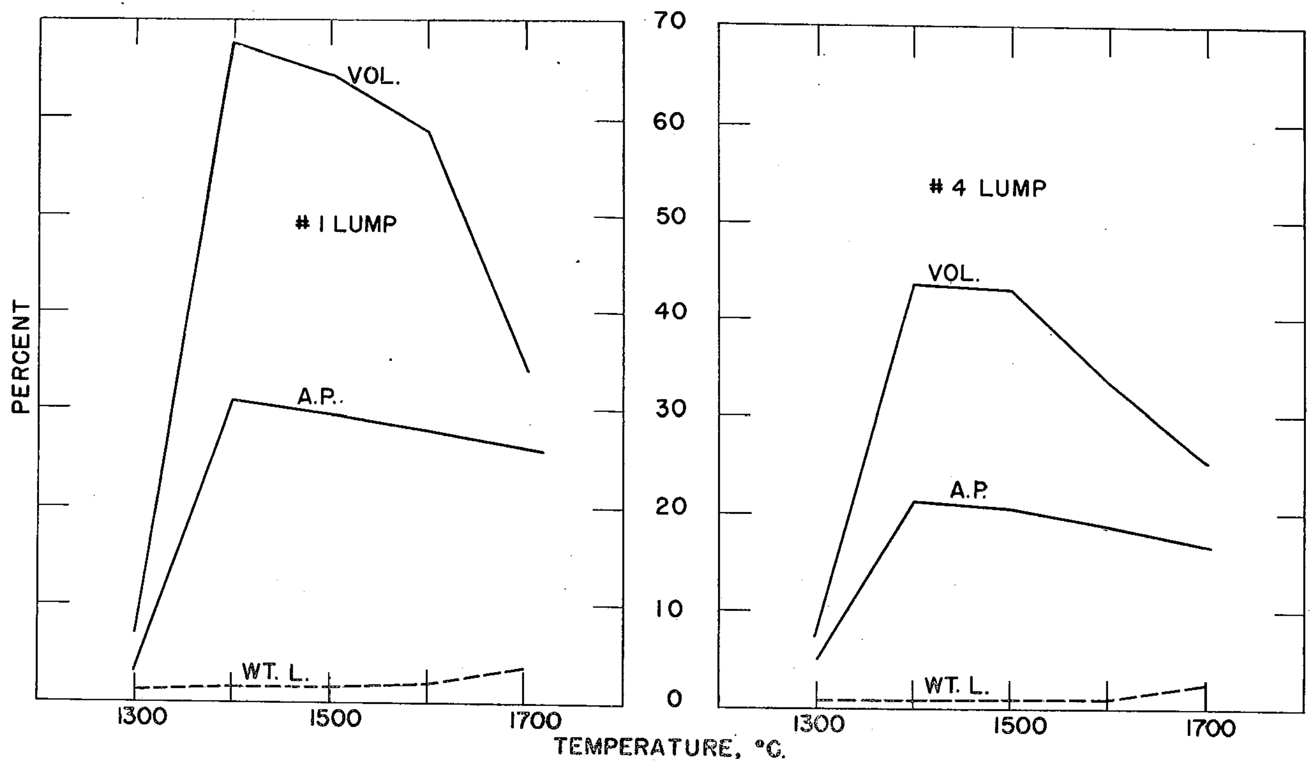

FIG. 14. THE MAXIMUM AND MINIMUM VOLUME EXPANSION AND POROSITY CHANGES OF SMALL FIRED MASSIVE KYANITE LUMPS

turing problems produced by shrinkage, yet if excessive, as in the case of the usual domestic kyanite concentrates, a volume increase may cause disintegration of molded structures during firing. The best massive India kyanite shows a comparatively small increase in volume and pore space on heating, but it is not pure kyanite, as separate boulders contain from 1 to over 80 per cent corundum.[17] The average may be as high as 10 per cent. The silica content of the Georgia samples was higher than the average of India kyanite and was present as quartz and sericite. The quartz was attached to the dornicks or was present in cracks. None was found associated with the kyanite in the two thin sections examined which showed a mosaic structure with random orientations of both tabular and acicular crystals. Where the kyanite mosaic was discontinuous, the spaces between the crystals were filled with sericite. The kyanite crystals had a maximum size of only a few millimeters and graded downward to very small dimensions. No corundum was noted in these sections. All of the Georgia lump samples showed a greater expansion than the best of the India corundum-kyanite but were very similar to that variety of India material, which showed either a parallel or radiating fibrous structure. Some of the curves resembled those India specimens which had a very coarse crystallization. Even though the fibrous structure of the Georgia lumps was either faintly developed or absent, their properties were comparable with those of the India fibrous specimens.

As shown in figure 14, the volume expansion for both samples started near 1300° C. and rose to a maximum at 1400° C. Above this temperature shrinkage occurred at different rates depending upon the type of kyanite. There was considerable shrinkage with both samples between 1400° C. and 1700° C. but at the latter temperature the lumps had not returned to their original size. The porosity curves showed similar characteristics, as the maximum porosity was attained when the lumps were heated to 1400° C. Brick made of kyanite calcined and fired at 1400° and 1500° were lighter and more porous than those treated at 1600°.

Although the expansion was greater than the India corun-

Figure 15. Top view of pile of Georgia massive kyanite lumps after heating to 1600° C. in a round oil-fired kiln. Three slagged areas on side walls show position of silicon carbide brick.

dum-kyanite, the strength of the Georgia calcined lumps was excellent. Splits and cracks formed in both foreign and domestic samples, but strong cohesion and toughness were common to both, and durable large particles were obtained by crushing.

Preparation of Kyanite for Brick Tests. The treatment of the two shipments was similar but differed in minor details. The boulders were washed, but the washing was more thorough for the second shipment. It was necessary to use a hose and scrub brush and then to dig the clay out of holes with a pointed tool. Representative 30-pound samples were selected from among the smaller lumps or broken from the larger and heated to a series of temperatures from 1300° to 1500° in the electric furnace, and to 1600° C. in an oil-fired furnace. No difference in the fired properties was noted between rounded lumps and the more irregular shapes.

After the first 260-pound shipment had been calcined to 1400° C. and 29 pounds of red-brown and black fused material had been chipped from the calcined boulders, an attempt was made to remove the iron constituents by magnetic separation. The high-intensity magnetic separator removed only 80 grams from the minus 8-mesh product. The non-magnetic portion remaining was 89 percent of the original sample but contained a large number of the dark grains.

A second batch of large and small lumps gave 82.5 per cent recovery. Pictures of this batch in the kiln after calcination and the best, medium, and poorest lumps are shown in figures 15, 16, 17, and 18, respectively. Although the photographs show considerable dark areas, in most cases the discoloration was not over ⅛ inch deep and represented the slight iron oxide penetration from the red soils, but occasional basic cohering minerals produced dark semimelted areas of 1-inch depth.

On heating, a rather surprising cleavage occurred with most lumps along the joint planes. The major splits were parallel to the length of the lump, but diagonal ones plus numerous ragged tear cracks of a few inches in length ran in all directions. Although a fracture along a joint plane showed pure white mullite without apparent (megascopic) glass or other indication of fluxing, cantilever portions were found bent out of shape or had fallen off completely due to their own weight (See figure 19). This action indicated the presence of a colorless flux probably sericite, between the original grains or of a melt similar to the eutectic between alumina and silica which formed during the heating process. The presence of glass was later confirmed by microscopic examination. This deformation did not reappear when the crushed fragments from these same calcines were united with a kaolin bond, refired, and reheated with and without a load to 1600° C.

Each sample of calcine was crushed in a large jaw crusher and passed through opened rolls in successive passes to produce the largest amount of coarse particles finer than 6-mesh. The cumulative screen analyses are given in table 4.

TABLE 4. *Cumulative screen analyses of calcined kyanite retained on screen, per cent*

Screen size	Temperature of calcination, °C.				
	1400*	1300	1400	1500	1600
6	0.0	3.1	0.9	1.8	2.8
8	0.0	25.3	16.8	23.3	21.8
10	5.7	46.0	36.1	44.8	40.0
14	14.9	58.5	47.5	56.5	50.4
20	25.6	67.1	55.9	64.6	57.9
28	36.2	73.0	62.1	69.8	64.0
35	44.9	77.5	67.2	73.9	69.2
48	53.8	81.6	72.7	77.9	74.6
65	62.2	85.4	78.4	82.1	79.8
100	71.8	89.2	84.4	86.6	85.5
150	78.9	91.7	88.6	90.2	89.7
200	84.7	93.9	91.8	93.0	93.0
Total	100.0	100.0	100.0	100.0	100.0

*First shipment ground to pass 8-mesh.

Based on the cumulative amounts coarser than 35-mesh, the calcines—arranged in order of increasing fineness—are those fired to 1300°, 1500°, 1600°, and 1400° C. This order may not be significant due to possible errors originating in the selection of the lump samples. The coarseness of the 1300° calcine was probably caused by the residual toughness of the original kyanite remaining after heating, since the inversion to the high temperature form of mullite was only partially complete. A microscopic examination showed that practically all of the kyanite heated to 1400° C. had inverted to mullite with some glass present.

The screen analyses show that a relatively coarse grog was obtained from the massive Georgia kyanite. As far as known, this has never been done with other domestic kyanites (with the exception of fibrous kyanite from a small deposit, now exhausted, north of Phoenix, Arizona) without the use of fluxes and hardening agents. The coarsest Appalachian kyanite concentrates of similar purity are finer than 35-mesh size and these fragile particles produce even more fines when calcined. The Georgia massive material, on the other hand, produced a tough coarser particle which resisted degradation during preparation and power pressing of full-size brick. The massive kyanite produced almost 70 per cent by weight of particles coarser than 35 mesh.

The chemical analyses of the different calcines are shown in table 5.

TABLE 5. *Chemical analyses of calcined massive Georgia kyanite, per cent*

	Temperature of calcination, °C.				
	1300	1400*	1400	1500	1600
SiO_2	39.7	38.8	38.5	39.0	38.3
Al_2O_3	57.6	60.1	60.1	59.6	60.2
Fe_2O_3	1.2	1.2	1.1	1.0	1.1
Total	98.5	100.1	99.7	99.6	99.6
Calculated kyanite	91.5	95.6	95.6	94.6	95.7

*First shipment.

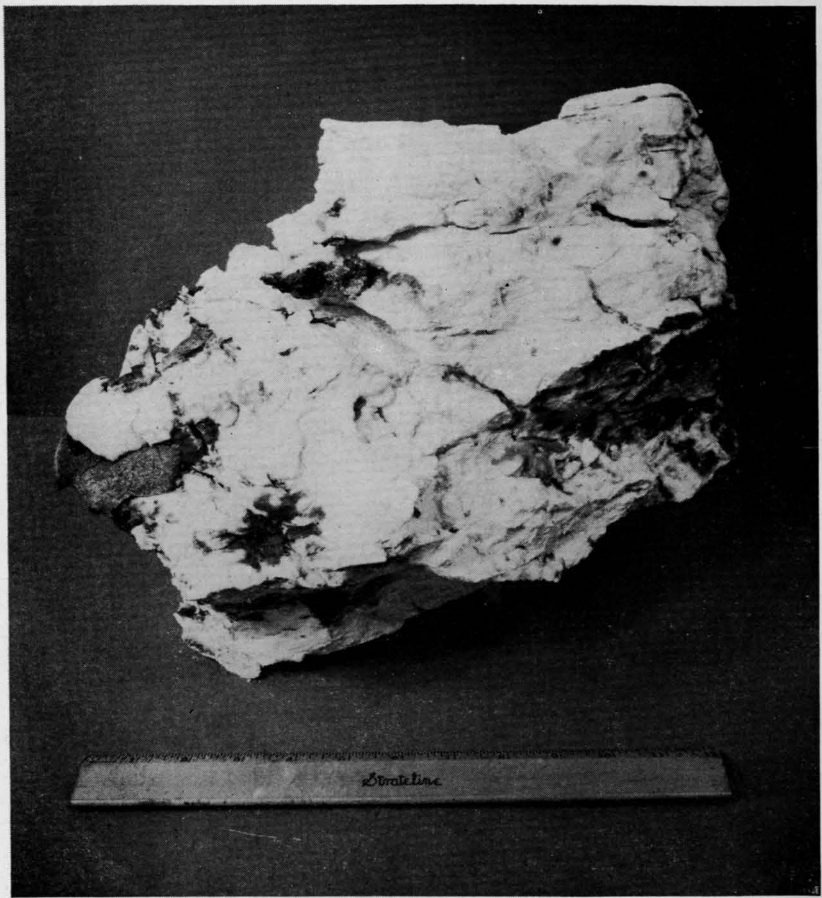

Figure 16. One of the best lumps after firing, showing a minimum of staining. Two patches of quartz inclusions are seen at the left.

Composition and molding of test brick. All brick mixtures contained 10 per cent of plastic, refractory Florida kaolin with 90 per cent of crushed kyanite grog. The temperature of grog calcination as noted above varied from 1300° to 1600° C. It was then separated into two particle sizes: A, From the first shipment, calcined to 1400° C. and ground to pass 8-mesh; and B, from the second shipment, calcined to variable temperatures and ground to pass 6-mesh.

The brick batches consisted of weighed portions of the dry grog and dry, fine, air-floated Florida kaolin. These were tempered with 5 per cent water and 2 per cent organic binder for a better dry strength and mixed thoroughly by hand. The brick were pressed at 5,000 pounds per square inch in a hydraulic press. After drying they were fired to various temperatures.

In tables 6, 7, and 8 the expression "weight of standard-size brick" refers to the calculated weight for a volume of 9 x 4.5 x 2.5 inches or 101.25 cubic inches.

Heat treatments. The original firing (called *preheat*) consisted of a total heating time of 12 to 13 hours including 4 to 5 hours holding at the maximum temperature. The *reheat* treatment followed the "Permanent Linear Change After Reheating of Refractory Brick" test method of the American Society for Testing Materials, A.S.T.M. C113-36 for superduty fireclay brick. This is similar to the U. S. Navy test, but the requirements of the two organizations for the highest refractoriness are different as follows:

U. S. Navy Department Specification 32B 2c, *March* 1, 1941

Class A—60 per cent alumina-diaspore brick.—

Alumina—The alumina content shall be not less than 57.5 nor more than 62.5 per cent.

Pyrometric cone equivalent—The pyrometric cone equivalent shall be not less than cone 35 (3,245° F.).

Permanent volumetric change—The permanent volumetric change after reheating at 2912° F. (1600° C.) for 5 hours shall be not more than plus 3 nor minus 1 per cent.

Spalling loss—The spalling loss after the simulative service test shall not exceed 8 per cent.

American Society for Testing Materials, C 27-41.

Superduty Fireclay Brick. A fireclay brick having a pyrometric cone equivalent not lower than cone 33 on the fired product, not more than 1 per cent linear shrinkage in the permanent linear change test, (1600° C.), and not more than 4 per cent loss in the panel spalling test (preheated at 1650° C.).

The *variable high-temperature load test* differs from the A.S.T.M. load test, which was designed to classify different manufactured products into general groups. In the variable load test the brick, standing on end and subjected to a load of 25 pounds per square inch, was heated on a standard schedule* beyond the temperature of maximum expansion to that temperature where rapid shrinkage occurred. The linear changes were measured during the heat treatment. In this way each brick was given a special treatment to determine its maximum temperature of good resistance. The "temperature range of constant maximum expansion" (plus or minus 0.1 per cent linear expansion) gives the maximum temperature of stability and usefulness. The "temperature of the 45° tan-

* McVay, T. N., Galbreath, W. W., Jr. and Allen, Dan: "Substitution of Kyanite, and Synthetic Mullite-Corundum for India Kyanite: IV", Jour. Amer. Ceram. Sec. 27, (9). September 1944, p. 281.

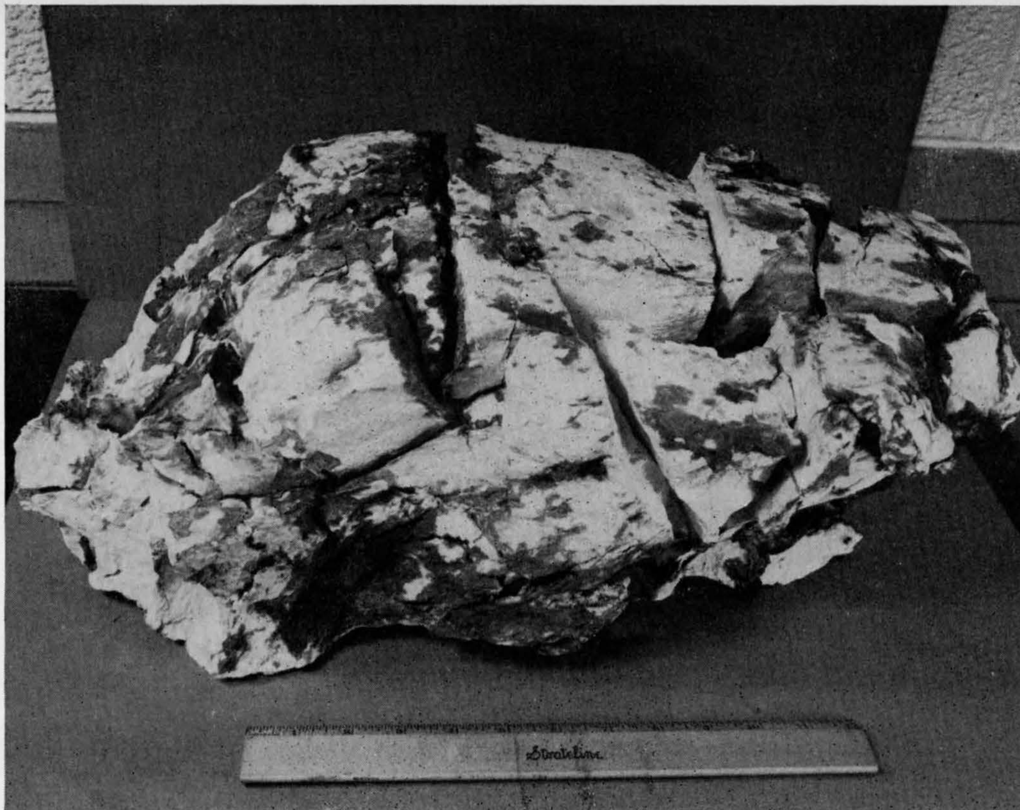

Figure 17. A large lump with about the average amount of slag or discolored spots. The expansion during heating has caused the typical splitting into one longitudinal crack with six cross splits and numerous small cracks.

gent" which occurs after the expansion is that where the tangent to the plotted standard curve of linear shrinkage is approximately 45°*. Here the shrinkage under load has become dangerously rapid.

The standard pyrometric cone equivalent test gave a P.C.E. of cone No. 36-37, which again indicates a composition and refractoriness close to pure kyanite.

Results. The data on the heat treatments of 15 full-sized brick are given in tables 6, 7 and 8. Tables 7 and 8 are continuations of table 6 with respect to the successive treatments of the brick. For example, brick numbered 8 and 9 were molded of grog which had been calcined to 1400° and fired as brick to 1600° (table 6). These brick averaged 7.5 pounds with 29.4 per cent pore space. Number 9 was reheated to 1600° (table 7) and because of 1.1 per cent volume shrinkage and a decrease in pore space, the equivalent weight of 101.25 cubic inches of this structure increased to 7.7 pounds. Number 8 was given the high-temperature load test (table 8). Where two or more brick have been given the same test, the data are averaged. Brick 4 was given a second reheat before its load test.

TABLE 6. *Properties of Georgia massive kyanite and India kyanite-corundum brick after preheating*

	Temp., °C.				Shrinkage		
Brick No.	Grog calc.	Brick preheat	Particle size	Porosity, per cent fired volume	Volume, per cent dry volume	Linear, per cent dry length	Wt. std. brick, lb.
1,2	1300	1600	B	35.7	28.3[1]	10.5[1]	6.7
3,4	1400	1475	A	32.0	3.8	.2[1]	7.2
5,6,7	1400	1600	A	29.6	3.1	1.2	7.5
8,9	1400	1600	B	29.4	5.6	1.2	7.5
10,11,12	1500	1600	B	28.9	4.8	1.5	7.5
13,14,15	1600	1600	B	26.2	3.4	.9	7.8
India	com.[2]	1500	A	24.8	----	.22	8.7
India[3]	average grade		----	23.0	----	----	8.7
India	best grade		----	20.0	----	----	9.1
India	poorest grade		----	25.0	----	----	7.8

1/Expansion.
2/Commercially calcined grog, brick of Norris manufacture.
3/Six grades of commercially manufactured brick from four companies.
*op. cit.

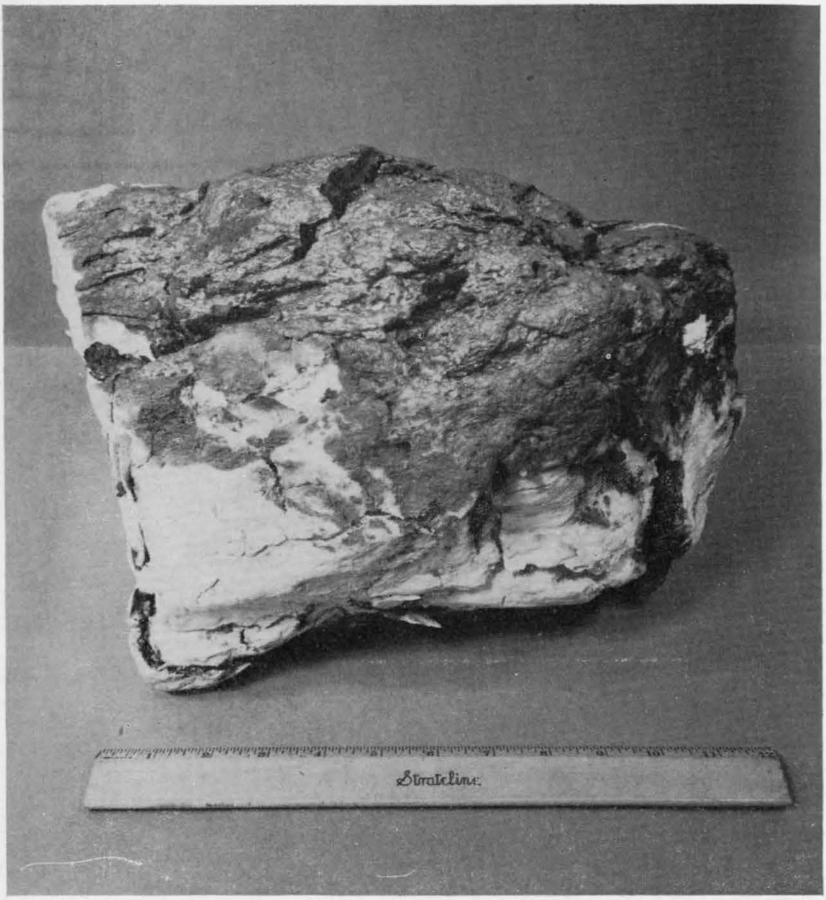

Figure 18. The worst slagged lump in the second or 800-pound shipment. The black slagged portion was about 1-inch deep.

TABLE 7. *Properties of Georgia massive kyanite brick after reheating to 1600° C.*

Brick No.	Porosity, per cent final volume	Shrinkage: Volume, per cent reheat volume	Shrinkage: Linear, per cent reheat length	Wt. std. brick, lb.
2	34.8	1.2	0.3	6.8
3,4	28.2	4.9	1.2	7.6
5,6,7	28.4	1.3	.2	7.6
9	28.7	1.1	.3	7.7
10,12	28.4	1.0	.4	7.7
14,15	26.8	1.0	.2	7.9

TABLE 8. *Variable temperature-load tests on Georgia massive kyanite and India corundum-kyanite brick*

Brick No.	Temp. range constant max exp., °C.	Max hot exp. per cent reheat length	Temp. 45°, tan., °C.
1	1140-1290	1.3	1390
4[1]/	1230-1480	.7	1540
6	1080-1480	.6	1540
8	1230-1450	1.7	1570
11	1190-1460	1.8	1510
13	1215-1420	2.0	1570
India[2]/	1420-1480	.08	1550
" average[3]/	1180-1360	.08	1420
" best	1170-1440	.05	1525
" poorest	1150-1260	.19	1315

1/High temperature load test after a second reheat test to 1600° C.
2/Commercially calcined grog, brick of Norris manufacture.
3/Six grades of commercially manufactured brick from four companies.

Discussion of Results.—In general, satisfactory "super-duty" refractories were made from the Georgia massive kyanite samples.

Thorough scrubbing and cleaning of the original Georgia lumps did not remove the brown iron oxide stain or all the attached low-melting minerals. Calcination was the best apparent method for clearly distinguishing between the kyanite and associated flux material. With the preparation method used for these tests, 20 to 33 per cent loss can be expected from the calcined lumps in rough commercial sorting. The loss was greater with the small lumps having greater exposed surfaces than with the larger. It may be possible to so learn the original appearance of the impurities that hand cobbing of the boulders will remove a larger percentage of the impurities before calcining, but crushing to a certain size may be necessary before cobbing. Hand cobbing after calcination, although easier due to the softening and fracturing of the lumps, will probably lead to a greater loss because of the penetration of fluxes at the high temperatures.

A coarse, compact, sturdy grog was obtained from the Georgia mineral and was similar to that furnished by the fibrous and coarse crystalline grades of India kyanite but not equal to the best India corundum-kyanite. Grog of the Georgia massive quality has never been obtained from other domestic kyanites by direct calcination of the original lumps. A coarse grog is desirable for quality of ware, ease of manufacturing, and production of spall-resistant refractories.

The Georgia massive kyanite grog was well bonded with 10 per cent plastic Florida kaolin. The fine domestic kyanite concentrates require a greater amount of clay bond with a consequent loss in refractoriness.

Standard-size brick made from Georgia kyanite were lighter in weight and had higher pore space than those made from the India corundum-kyanite.

The sample brick when fired to 1600° C. met the A.S.T.M. reheat specifications for superduty fire brick and it is probable that they can be made sufficiently volume-constant to meet the Navy specifications.

The load resistance of the Georgia kyanite sample brick at high temperatures was very satisfactory.

Laboratory work to be done.—Brick firing or preheating to temperatures between 1400° and 1600° C. may be satisfactory, but these tests have not been made yet at Norris. Commercial brick are fired to 1600° C. (nearly pyrometric cone 26) only for a few special refractories because of the difficulties and cost in reaching this temperature in quantity production. The India corundum-containing kyanite has a distinct advantage by attaining lower porosity, a greater weight per unit volume, and stability at lower firing temperatures. Tests should also be made of the spalling resistance of the Georgia material. More brick are being prepared for the U. S. Navy tests at Philadelphia and for commercial firing and commercial service tests.

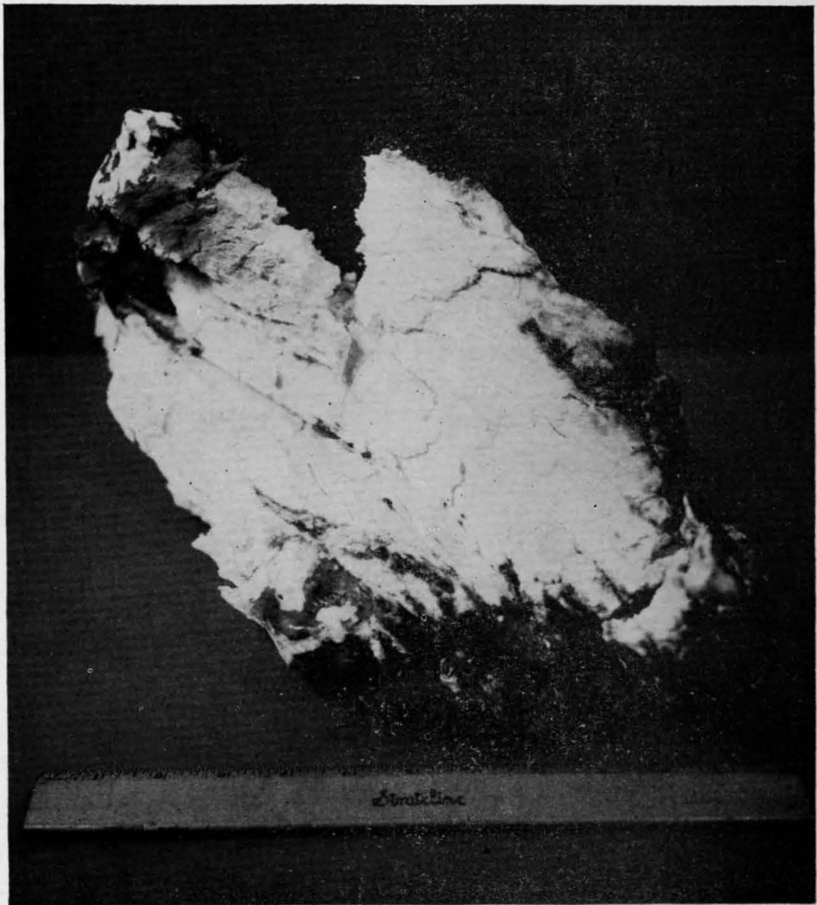

Figure 19. One-half of this lump split and fell off during firing leaving the white interior exposed. The top left portion has fallen away in a pyroplastic fashion from a position of alignment with the central pinnacle.

Recommendations. Although the above tests showed that the selected Georgia massive kyanite samples did not equal the best corundum-kyanite from India, they have indicated a superiority to the domestic kyanite concentrates in manufacturing refractory shapes, and a stability at high temperatures. If such high-quality brick can be manufactured on a commercial scale a desirable superduty product can be placed on the domestic market. The commercial development depends primarily on whether commercial quantities of selected, high-grade, massive kyanite can be obtained. In the meantime, laboratory and commercial manufacturing tests should be continued.

REFERENCES

1. Bayley, W. S., Geology of the Tate quadrangle, Georgia: Ga. Geol. Surv. Bull. 43, 1928.

2. Billings, Katharine Fowler, Sillimanite deposits in the Monadnock Quadrangle New Hampshire: New Hampshire State Planning and Development Commission, Mineral Resources Survey, Concord, N. H., 1944.

3. Dunn, J. A., Aluminous refractory materials: Cyanite, sillimanite, and corundum in Northern India: Geol. Surv. India Memoirs, 52, 1929, pp. 145-274.

4. Dunn, J. A., The aluminous refractory materials: Kyanite, sillimanite, and corundum in Western India: The Mining Journal, London, Nov. 2, 1929, p. 876.

5. Forrester, J. D., A sillimanite deposit near Troy, Latah Co., Idaho: Idaho Bur. Mines, Pamph. 59, Nov., 1942, 10 pp.

6. Furcron, A. S., James River iron and marble belt, Virginia: Va. Geol. Surv. Bull. 39, 1935.

7. Furcron, A. S., Geology and mineral resources of the Warrenton quadrangle, Virginia: Va. Geol. Survey Bull. 54, 1939, pp. 37-41.

8. Furcron, A.S., and Teague, Kefton H., Mica-bearing pegmatites of Georgia: Ga. Geol. Surv. Bull. 48, 1943.

9. Geologic map of Georgia: Georgia Division of Mines, Mining and Geology, 1939.

10. Harker, Alfred, Metamorphism: Methuen and Co., London, 1932, 360 pp.

11. Hudson, W. C., Sillimanite found in South proves important: Eng. and Min. Jour., Sept., 1944, p. 81.

12. Huer, R. P., Kyanite refractories: Brick and Clay Record, 100 (3), 1942, pp. 50-51.

13. Jonas. Anna I., Kyanite in Virginia: Va. Geol. Surv., Bull. 38, 1932.

14. Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Nantahala folio (No. 143), 1907.

15. Knopf, Eleanora Bliss, Retrogressive metamorphism and phyllonitization: Amer. Jour. Science, Vol. 21, Jan. 1931, pp. 1-27.

16. LaForge, L. and Phalen, W. C., U. S. Geol. Survey Geol. Atlas, Ellijay folio (No. 187), 1913.

17. McVay, T. N., and Wilson, Hewitt, Substitution of topaz, domestic kyanite, and synthetic mullite-corundum for India kyanite, 1-111: Jour. Am. Cer. Soc., Vol. 26, No. 8, August, 1943, pp. 252-64.

18. Pascoe, Sir. Edwin, General report for 1927 (quotes A. J. Dunn): Geol. Surv. of India, Vol. LXI, pt. 1, 1928, pp. 68-71.

19. Peach, Benjamin Neve, and Horne, John, Chapters on the geology of Scotland: Oxford University Press, 1930.

20. Phemister, J., Scotland the Northern Highlands: Geological Survey and Museum, Edinburgh, 1936.

21. Prindle, Lewis M., and others, Kyanite and vermiculite deposits of Georgia: Ga. Geol. Surv. Bull. 46, 1935.

22. Simpson, E. S., Andalusite and sillimanite, Ninghanboun Hills, S. W. Division: Jour. of the Royal Society of Western Australia, Vol. XVII, 1930-31, pp. 138-39.

23. Simpson, E. S., Sillimanite, Toodyay and Clackline, S. W., and Kyanite, Clackline: Jour. of the Royal Soc. of Western Australia, Vol. XXII, 1936, pp. 10-13.

24. Smith, Lawrence L., Sillimanite in South Carolina: Eng. and Min. Jour., Aug. 1943.

25. Smith, Richard W., The kyanite industry of Georgia: Am. Inst. Min. and Met., Tech. Pub. No. 742, 1936.

26. Stose, George W. and Stose, Anna Jonas, The Chilhowee group and Ocoee series of the Southern Appalachians: Amer. Jour. Sci., Vol. 242, Aug. 1944, pp. 401-416.

27. Stuckey, J. L., Cyanite deposits of North Carolina, Econ. Geol. Vol. 27, 1932, pp. 670-673.

28. Stuckey, J. L., Origin of Cyanite: Econ. Geol. Vol. 30, 1935, pp. 444-450.

29. Watson, Thomas L., Preliminary report on a part of the granites and gneisses of Georgia: Ga. Geol. Surv. Bull. 9-A, 1902.