Kyanite, Sillimanite, and Andalusite Deposits of the Southeastern States

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By GILBERT H. ESPENSHADE *and* DONALD B. POTTER

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KYANITE, SILLIMANITE, AND ANDALUSITE DEPOSITS OF THE SOUTHEASTERN STATES

By GILBERT H. ESPENSHADE and DONALD B. POTTER

ABSTRACT

Deposits of the Al_2SiO_5 minerals—kyanite, sillimanite, and andalusite—in the Southeast were investigated during 1950 to 1953. These minerals, particularly kyanite, are useful in the manufacture of high-alumina refractory materials. Deposits in the Southeast have been important sources of kyanite since the 1920's.

These deposits occur in the large area of metamorphic rocks in the Blue Ridge and Piedmont provinces that extends for nearly 700 miles from the Potomac River to central Alabama. The Al_2SiO_5 minerals are found here in four major types of deposits: (a) in quartzose rocks, (b) in micaceous schists and gneisses, (c) in quartz veins and pegmatites, and (d) in residual soils and placers. The quartzose deposits generally have a higher content of Al_2SiO_5 minerals than the other deposits; kyanite-quartz deposits have been the most productive in the region.

Kyanite-quartz rock, sillimanite-quartz rock, and andalusite-pyrophyllite-quartz rock are the main varieties of quartzose deposits in the region; they seem to be more numerous in the Southeast than in other parts of the country. Although these varieties differ in their mineral content and other geologic features, they are similar in chemical composition, consisting principally of SiO_2 and Al_2O_3.

Deposits of kyanite-quartz rock are the largest and most numerous of the group. Kyanite and quartz are the predominant minerals; kyanite generally constitutes 10 to 30 percent of the rock; muscovite is generally present, and rutile is a widespread but minor constituent, generally in amounts between ½ and 1 percent; pyrite is also common; other minor constituents in some deposits are pyrophyllite, lazulite, topaz, and clay minerals. The deposits have a great range in size. The largest and most persistent are in the Farmville district, Virginia, the Kings Mountain district, North Carolina-South Carolina, and at Graves Mountain, Ga. The rock is extremely resistant to weathering and erosion, and the larger deposits form prominent ridges or monadnocks several hundred feet high and a mile or more long. Sillimanite quartzite deposits are small, few in number, and have been found only in the Kings Mountain district, North Carolina-South Carolina. Sillimanite makes up from 10 to 35 percent of this rock; andalusite and kyanite are also present in places. Other aluminous minerals occurring locally in amounts of a few percent are white mica, chloritoid, diaspore, topaz, and lazulite; rutile is a widespread accessory mineral. Significant amounts of andalusite, generally accompanied by a little diaspore, are present in some of the North Carolina pyrophyllite deposits; small amounts of kyanite, topaz, corundum, and lazulite are also present locally; rutile is a persistent accessory mineral. A new deposit of this type was discovered at Boles Mountain, S.C., during the present investigation. Very fine grained topaz is the most abundant aluminous mineral in parts of the Brewer deposit, South Carolina; andalusite, kyanite, and pyrophyllite are also present.

Kyanite occurs in micaceous schist and gneiss in extensive areas of the Blue Ridge of western North Carolina and northern Georgia. The kyanite content of large bodies of rock ranges from a few percent to about 10 percent, though some individual layers contain 15 percent or more. Several deposits of this type have been mined in North Carolina and Georgia. Sillimanite schist is rather widespread in a belt in the western Piedmont that extends from North Carolina to eastern Georgia, and in another belt in the Blue Ridge of North Carolina and Georgia. Sillimanite usually is in very fine crystals that are intimately intergrown with mica; it generally forms less than 10 percent of the rock. Sillimanite schists have been explored rather extensively, but none have been mined. Large crystals of kyanite are common in quartz veins and pegmatites in the kyanite schist areas of the Blue Ridge. Such deposits are small and irregular, and attempts to mine them have not been successful. In the kyanite schist belt of Habersham and Rabun Counties, Ga., kyanite has accumulated in the residual soil and in stream placers; these deposits have been mined at several places. Kyanite and sillimanite are among the heavy minerals in sandy formations of the Atlantic Coastal Plain.

We believe that the kyanite and sillimanite in the micaceous schists and gneisses were formed by the metamorphism of aluminous sedimentary rocks. Some geologists have thought that the alumina was brought in by hydrothermal solutions, possibly from igneous sources, and regard the kyanite-bearing quartz veins and pegmatites that occur in kyanite schist and gneiss as having been the agents that introduced alumina. However, this is quite unlikely, because kyanite in the quartz veins and pegmatites appears to be younger than kyanite in the country rock; alumina probably was transferred from the country rock to the quartz veins and pegmatites.

On the other hand, the quartzose deposits of Al_2SiO_5 minerals seem to have been formed by two distinct modes of origin: metamorphism of aluminous sedimentary rocks and by hydrothermal activity. Both types occur with, or in the vicinity of, volcanic rocks. Kyanite quartzite in the Farmville district, Virginia, and kyanite quartzite and sillimanite quartzite in the Kings Mountain district, North Carolina-South Carolina, are folded concordantly with the other metamorphic rocks and have the distribution patterns of stratigraphic units. There seem to be only two possible modes of origin for the high-alumina quartzite deposits in these districts: either by the metamorphism of clay-sand sediments or by the introduction of alumina selectively into sandstone beds. There is no evidence for large-scale introduction of alumina,

and the alumina in these deposits is considered to have been a primary constituent of the sediment. High-alumina quartzose deposits that appear to be of replacement origin include the pyrophyllite deposits, the topaz-rich deposit at the Brewer mine, South Carolina, and the kyanite-quartz deposits at Hagers Mountain, N.C., Corbett property near Smithfield, N.C., Little Mountain, S.C., and Graves Mountain, Ga. These deposits are all irregular and lenticular, and occur in a belt of volcanic flows, tuffs, and slates in the eastern Piedmont. Some of the evidence for replacement are relic quartz phenocrysts in the Graves Mountain deposit and relic breccia and bedding structures in silicified rock of other deposits. These high-alumina quartzose deposits may have been formed by some sort of hydrothermal leaching process that removed nearly all constituents except silica, alumina, and titania; this leaching was possibly accomplished by solfataric activity or some similar process in areas of volcanism. Some modifications of the mineral content, without change in chemical composition, may have occurred later through metamorphism.

Domestic production of Al_2SiO_5 minerals since 1950 has consisted of kyanite concentrates from mines at Baker Mountain and Willis Mountain, Va., and Henry Knob, S.C., and of andalusite contained in pyrophyllite ore from some pyrophyllite mines in North Carolina. Kyanite was formerly produced in quantities from the Clarkesville district, Ga., and from Celo Mountain, N.C. Measured and indicated reserves of kyanite-quartz rock (containing 10 to 30 percent kyanite) minable by opencut methods in the Southeastern deposits are estimated to be 100 million tons. Kyanite and sillimanite schist and gneiss occur in much larger quantities, but their content of Al_2SiO_5 minerals rarely exceeds 10 percent. Knowledge of the andalusite-pyrophyllite deposits is rather slight; the larger ones may contain between 1 and 2 million tons of inferred ore of unknown andalusite content to a depth of 100 feet.

The quartzose deposits were studied more thoroughly than the other types, and the geology of about 105 square miles was mapped in detail in the vicinity of kyanite quartzite deposits in the 2 producing districts—Farmville district, Virginia, and Kings Mountain district, North Carolina-South Carolina. Many deposits of the three other types were examined only briefly, and much of the information on these deposits has been taken from reports of other workers.

The principal rocks in the Farmville district, Buckingham, Prince Edward, and Charlotte Counties, Va., include kyanite quartzite, hornblende gneiss, and several varieties of mica schist and gneiss, all of probable Precambrian age. Pegmatites and quartz veins are abundant. Granite bodies occur near the district, but they are not found in the vicinity of the kyanite deposits. The kyanite quartzite underlies only a small part of the mapped area, but it is the most useful mapping unit because it is distinctive and seems to occur at about the same stratigraphic position throughout the district. Underlying rocks are mainly biotite gneiss with some hornblende gneiss, whereas the dominant rock overlying the kyanite quartzite is hornblende gneiss. The kyanite quartzite probably was originally a thin bed of argillaceous sandstone in a thick series of graywacke and basaltic lava. These rocks have been highly folded and uniformly metamorphosed in the amphibolite facies.

Extensive outcrops of kyanite quartzite outline the large asymmetric Whispering Creek anticline at the northern end of the district. A kyanite quartzite bed between 5 and 40 feet thick is exposed continuously for about 5½ miles along the east flank of this fold. Kyanite quartzite forms several discontinuous segments in a distance of 2½ miles on the steep west limb of the fold; the outcrop width reaches 300 feet here where beds are repeated by isoclinal folding. The conspicuous ridge of Willis Mountain is formed by the thickened beds on the west limb of the fold. Aggregates of massive kyanite occur in rodlike bodies, as much as 90 feet long, that are elongated parallel to minor fold axes and lineation on the west limb of the anticline. Kyanite quartzite beds are complexly folded also in the other larger deposits of the district: Baker Mountain, Woods Mountain, Madisonville, and Leigh Mountain. The fold at Woods Mountain probably is a recumbent anticline whose compressed limbs are folded into several minor anticlines and synclines that plunge gently northeast.

Reserves of kyanite quartzite in the Farmville district minable by opencut methods are estimated to be 50 million tons containing between 10 and 30 percent kyanite.

In the Kings Mountain district, North Carolina–South Carolina, kyanite and sillimanite quartzites are associated with quartzite, conglomerate, and white mica schists; these associated rocks locally contain the aluminous minerals kyanite, andalusite, staurolite, and chloritoid. The aluminous quartzites occur in lenses and beds in irregularly curving zones that reflect several large folds and innumerable minor folds. These beds are as much as 35 feet thick, but their outcrops are much wider in closely folded areas. The aluminous quartzites seem to have been originally clay-rich sandstone beds in a thick series of clastic and tuffaceous sediments, pyroclastic rocks, and lavas. This group of rocks seems to overlie uncomformably a thick sequence of biotite schist and gneiss and hornblende gneiss; these older rocks are mainly metamorphosed lavas (soda rhyolite, andesite, and basalt) intruded by tonalite and quartz gabbro. These two groups of rocks may be of late Precambrian or early Paleozoic age. They are folded along northeasterly trends, and intruded by the large north-trending body of Yorkville quartz monzonite (Early Mississippian?). The metamorphic rocks have been twice folded and perhaps twice metamorphosed. The degree of metamorphism decreases, from the amphibolite facies near the Yorkville quartz monzonite, to the albite-epidote amphibolite facies, and to the greenchist facies. Kyanite occurs in rocks of all three facies, but sillimanite is present only in rocks of the amphibolite facies near the quartz monozite contact or in schist septa within the quartz monzonite.

In the southern part of the district the aluminous quartzite deposits lie on the west side of the quartz monzonite body: the important kyanite quartzite deposits are at Crowders Mountain, The Pinnacle, and Henry Knob; the principal sillimanite quartzite deposits (near the quartz monozite) are on the Will Knox and Ryan-Purcley properties. In the northern part of the district the aluminous quartzite deposits are on the east side of the quartz monzonite; the sillimanite quartzite deposit of Reese Mountain is less than 1 mile from the contact, and the Clubb Mountain kyanite quartzite deposit lies about 2 miles farther east.

Reserves of kyanite quartzite in the district minable by opencut methods are estimated to be 40 million tons containing 10 to 30 percent kyanite. Minable reserves of sillimanite quartzite to depth of 100 feet are estimated at 300,000 tons containing about 30 percent sillimanite.

Deposits of kyanite-quartz rock in other regions that are described in less detail in the present report are in Halifax County, Va.; at Hagers Mountain, Person County, N.C.;

Corbett deposit near Smithfield, Johnston County, N.C.; Cherokee and York Counties, S.C.; Little Mountain, Newberry County, S.C.; and Graves Mountain, Ga. The principal deposits of kyanite schist and gneiss described are in the Burnsville–Swannanoa area, Buncombe, Yancey, and Mitchell Counties, N.C., and in the Clarkesville district, Habersham and Rabun Counties, Ga. The major deposits of sillimanite schist described are in the Piedmont belt of North Carolina, South Carolina, and Georgia and in the Blue Ridge of North Carolina and Georgia. Andalusite-pyrophyllite-quartz deposits described are at Bowlings Mountain, Hillsboro, Snow Camp, and Staley, N.C., and at Brewer gold mine and Boles Mountain, S.C.

INTRODUCTION

During the present century the aluminum silicate minerals kyanite, sillimanite, and andalusite (each with the same chemical composition Al_2SiO_5) have become industrially important in the manufacture of various ceramic articles used at high temperatures. Industrial application of the Al_2SiO_5 minerals followed the discovery during World War I that the high-quality porcelain required in spark plugs for airplane engines could be made from material having this chemical composition. Various other articles capable of withstanding the high temperatures of different industrial processes have since been developed. The Al_2SiO_5 minerals and other high-alumina substances are widely used now, principally in the manufacture of refractory linings for metallurgical and glass furnaces, boilers, and kilns.

Kyanite has been the principal Al_2SiO_5 mineral used because it has generally been found in higher grade deposits than either andalusite or sillimanite. The Al_2SiO_5 minerals consumed by the domestic industry have come mainly from deposits in the Southeastern States, California, and Nevada and from ores imported from India, Keyna, and the Union of South Africa. The entire domestic production of these minerals since 1950 has consisted of kyanite concentrates from two mines in Virginia and one in South Carolina, and of andalusite contained in pyrophyllite ore from some pyrophyllite mines in North Carolina.

The imported kyanite is a crystalline aggregate that forms a better bond in refractory bricks than does the fine-grained domestic kyanite concentrate; it has become known as strategic-grade kyanite because it has been essential for certain purposes. The lack of such high-quality kyanite in the United States has stimulated interest in domestic deposits during recent years. However, synthetic mullite is now being made from domestic raw materials; this product is as good as mullite made from imported strategic-grade kyanite. This report presents the results of an investigation by the Geological Survey, from 1950 to 1953, of deposits of the Al_2SiO_5 minerals in the Southeastern States.

PREVIOUS STUDIES

Kyanite has been known for many years at numerous localities in the metamorphic belt of the Southeast, but only a few geologic studies were made of these deposits before the development of kyanite as an industrial mineral. The more important of these studies were those of Graves Mountain, Ga., by Watson and Watson (1912), in the Tate quadrangle, Georgia, by Bayley (1928), and in the Gaffney and Kings Mountain quadrangles, North Carolina–South Carolina, by Keith and Sterrett (1931). Prospecting and mining of the deposits began shortly after 1920, and many articles describing the kyanite deposits and the mining operations have since appeared. The principal papers are as follows: Kyanite in Virginia by Jonas (1932) and Watkins (1932), in North Carolina by Stuckey (1932) and Chute (1944), in South Carolina by L. L. Smith and Newcome (1951), and in Georgia by R. W. Smith (1936), Prindle and others (1934), and Furcron and Teague (1945). A general review of kyanite and sillimanite deposits in the Southeast has been given by Furcron (1950).

Sillimanite had been found at a few localities many years ago, but it is only recently that it has been recognized as widespread in the schists of certain areas. The possibility that sillimanite might be substituted for kyanite imported from India encouraged the exploration of these deposits during and since World War II. This work was carried on mainly by the U.S. Bureau of Mines and by the Tennessee Valley Authority in cooperation with the geological surveys of the States of North Carolina, South Carolina, and Georgia. Sillimanite deposits in North Carolina have been described by Hunter and White (1946) and Hash and Van Horn (1951), in South Carolina by L. L. Smith (1945), Hudson (1946), Hickman (1947), and Dosh (1950), and in Georgia by Furcron and Teague (1945) and Hudson (1946). General reviews of the sillimanite deposits have been given by Teague (1950) and Furcron (1950). The zone of sillimanitic rocks in South Carolina and North Carolina has been discussed in a paper on the geology of the inner Piedmont by Overstreet and Griffitts (1955).

Andalusite was not known to occur in important amounts in the region until it was discovered recently to be associated with other high-alumina minerals—diaspore and topaz—in several pyrophyllite deposits in North Carolina. A preliminary report on these occurrences has been given by Broadhurst and Councill (1953). The occurrence of topaz at the Brewer mine, South Carolina, has been described by Fries (1942); kyanite, andalusite, and pyrophyllite are also present in the deposit.

PRESENT INVESTIGATION

The present geologic study of the Southeastern deposits of kyanite, sillimanite, and andalusite was begun in 1950 in order to gather more information on their distribution, characteristics, origin, and potential reserves. All the important districts and deposits known in the region were examined. Particular attention was given to the kyanite quartzite deposits; detailed geologic maps were made of these deposits and the areas surrounding them in the two producing districts—the Farmville district of central Virginia and the Kings Mountain district of North Carolina and South Carolina. In the Farmville district, both of us took part in the initial stage of the work, and Espenshade completed the fieldwork. The geology of the Kings Mountain district was mapped by Potter. Geological maps were made of half a dozen deposits of kyanite-quartz rock outside these two districts. Other kyanite deposits in the region were examined only briefly, because we believed either that adequate studies had been made previously by others or that the deposit in question seemed to be of minor importance.

The sillimanite deposits in North Carolina, South Carolina, and Georgia had been investigated widely by others since 1945; and, inasmuch as no deposits of definite economic value had been discovered, we did not make a detailed study of them. Some of the important and representative localities were visited. Several small sillimanite quartzite deposits in the Kings Mountain district, North Carolina–South Carolina, were discovered during the present study.

In the course of a brief examination of the North Carolina pyrophyllite deposits for the purpose of comparing their geologic features with the kyanite deposits, it was learned from J. L. Stuckey and S. D. Broadhurst, of the North Carolina Division of Mineral Resources, that they had recently discovered andalusite in several of the pyrophyllite deposits. We examined these deposits carefully, but did not map them geologically because they were being investigated by the North Carolina Division of Mineral Resources. Andalusite was discovered by Espenshade to be associated with pyrophyllite and quartz at several localities in South Carolina, but it occurs in very minor amounts in all except one of the deposits.

This report summarizes all the geologic information now available (1959) on the kyanite, sillimanite, and andalusite deposits of the Southeastern States. Most of the information concerning the kyanite quartzite deposits—the most important group in the region—was obtained from our field studies. A preliminary statement about these deposits has already been given (Espenshade and Potter, 1953). Much of the information on the other kyanite deposits and on the sillimanite deposits was taken from publications of other workers. Information contributed by D. A. Brobst, N. E. Chute, and P. K. Theobald, Jr., of the Geological Survey, on some kyanite deposits in western North Carolina is used in this report. Information on andalusite in North Carolina comes not only from our studies but also from the paper by Broadhurst and Council (1953).

ACKNOWLEDGMENTS

Many persons have contributed data or useful services during this investigation. The cooperation of the managers of the two kyanite mining companies, Gene Dixon, of the Kyanite Mining Corp. at Baker Mountain and Willis Mountain, Va., and Albert R. Eckel, of Commercialores, Inc., at Henry Knob, S.C., has been most helpful. Valuable information has come from J. L. Stuckey and S. D. Broadhurst, of the North Carolina Division of Mineral Resources; from L. L. Smith, State Geologist of South Carolina, and B. F. Buie, formerly with the South Carolina Research, Planning and Development Board; from Garland Peyton and A. S. Furcron, of the Georgia Department of Mines, Mining and Geology; and from C. E. Hunter, formerly geologist with the Tennessee Valley Authority. We thank our associates in the U.S. Geological Survey and persons in the U.S. Bureau of Mines who have discussed various problems with us and who have contributed information or useful services. P. K. Theobald, Jr., and L. A. Brubaker, of the Geological Survey, each assisted for about 1 month in the field studies. D. H. Ritcher and others studied a collection of mica specimens from some of the kyanite deposits. This report has benefited from the thorough critical reviews by W. C. Overstreet and J. J. Norton.

REGIONAL GEOLOGY

The kyanite, sillimanite, and andalusite deposits of the Southeastern States are in the large area of metamorphic rocks of the Piedmont and Blue Ridge provinces that extends for nearly 700 miles from the Potomac River to central Alabama. The rolling surface of the Piedmont province slopes gently eastward from altitudes of 1,000 to 1,500 feet at the base of the Blue Ridge to between 200 and 300 feet at the Fall Line, the west edge of the Coastal Plain. Low mountains are common in the western part of the Piedmont province; only a few isolated monadnocks are found farther east. The rocks of the Piedmont province are overlapped on the east and on the south by the Coastal Plain sedimentary rocks of Cretaceous and Tertiary age that dip gently seaward. The Blue Ridge province is a rugged, mountainous region that is bordered on the west by the folded sedimentary rocks of Paleozoic age of the Appalachian Valley and Ridge province. The mountains are 5 to 10 miles wide in Virginia, but they become wider to the south and are over 60 miles across in southwestern North Carolina.

The region is well populated, and good highways and railroads provide excellent transportation. The climate is moderate; even in the Blue Ridge long periods of severe winter weather are rare.

Two general types of metamorphic rocks predominate in the region: hornblende schists and gneisses and micaceous siliceous schists and gneisses. These rocks have been considered to be Precambrian in age in some areas and Paleozoic in other places; metamorphosed rocks of both ages are probably present. Much of the hornblende schist and gneiss was probably igneous rock originally, either intrusive rocks or flows of intermediate to basic composition. Some hornblende schist and gneiss appear to be metamorphosed sedimentary rocks. The hornblende-bearing rocks have been called the Roan gneiss in the southern part of the region. Many of the micaceous siliceous schists and gneisses were originally sedimentary beds; some show relict volcanic structures, and others may have been intrusive igneous rocks. In the northern part of the region, large areas of these rocks have been called the Wissahickon schist; in the southern part, similar rocks have been called the Carolina gneiss. Kyanite, sillimanite, and andalusite occur chiefly in the different varieties of micaceous siliceous gneisses and in associated quartzose rocks.

Large granite bodies occur in parts of the region, and pegmatites are abundant in certain areas. Gabbro and diorite are common; small bodies of ultrabasic rocks occur mostly in the Blue Ridge area. A large area in central North Carolina is underlain by volcanic flows, tuffs, and slates, some of which are but slightly metamorphosed; this area has become known as the Carolina slate belt. These rocks extend southwest across South Carolina into Georgia, where they have been called the Little River series. Isolated basins of unmetamorphosed sedimentary rocks of Triassic age occur in the Piedmont of Virginia and North Carolina. Widely distributed diabase dikes cut the Triassic sedimentary rocks and the metamorphic rocks.

The distribution of some of these major geologic units—the belts of volcanic rocks, the late Paleozoic granitic bodies, pegmatites, and basins of Triassic sedimentary rocks—is shown on the map of the Southeastern States (pl. 1); the map also shows the location of the kyanite, sillimanite, and andalusite deposits. Current knowledge of, and ideas about, the geology of the central part of the Appalachians have recently been discussed in a review article and shown on a geologic map by King (1955).

The geologic structure of the region is highly complex. The rocks generally are strongly folded, and have a foliation which is some places completely obscures the original bedding. As a rule, the geologic units trend toward the northeast; the mountains and ridges of the region also have the same trend. The degree of regional metamorphism varies from place to place; metamorphic grade ranges from slightly deformed and metamorphosed shaly beds in the Carolina slate belt to sillimanite schists associated with granite and pegmatite.

The rocks in the region have undergone deep weathering for long periods of time, and exposures of fresh rock are rare in many places. Most rocks have been decomposed by chemical weathering. The less resistant minerals, such as feldspar and hornblende, are altered to clay; the more resistant minerals, such as quartz, kyanite, sillimanite, and muscovite, are little altered. The original structure of the rock is generally well preserved in the rotted rock. This mantle of decomposed rock, known as saprolite, extends to depths of 50 to 100 feet in some places. Fresh rock is found most commonly along streams where the saprolite has been removed by erosion. Rocks that are made up principally of resistant minerals are generally only slightly decomposed. Kyanite-quartz rock is very resistant and forms some of the prominent isolated knobs and ridges in the Piedmont province.

GEOLOGY OF THE DEPOSITS

Kyanite, sillimanite, and andalusite have the same chemical composition—Al_2SiO_5—but different physical properties. These minerals characteristically occur in metamorphic rocks where they have been formed by recrystallation of rocks of appropriate chemical composition under the influence of heat, and possibly pressure. Generally, only one of the Al_2SiO_5 minerals is present in a deposit, but it is not uncommon for two of them to occur together, and all three are found together at a few places. The conditions of formation of the different Al_2SiO_5 minerals are only poorly understood; this problem is discussed further in the section on origin of the deposits.

Kyanite (formerly spelled "cyanite") crystallizes in the triclinic system as long-bladed crystals with 1 perfect cleavage and 1 fair cleavage; its most common colors are blue, gray, white, and green; its hardness on the perfect cleavage face varies with direction, being between 4 to 5 parallel to the length of the crystal, and 6 to 7 at right angles to the length; its specific gravity ranges from 3.56 to 3.67.

Sillimanite crystallizes in the orthorhombic system as long slender fibrous or needlelike crystals, which may form masses of columnar or radiating structure; it has one perfect prismatic cleavage; the color may be white, gray, green, or brownish; its hardness is between 6 and 7; the specific gravity is 3.23 to 3.25.

Andalusite also crystallizes in the orthorhombic system, but commonly in coarse prismatic or granular crystals; it has 1 good and 1 fair cleavage; its colors are commonly white, light gray or bluish gray, pink, green, and brown; the hardness is 7.5; its specific gravity is 3.1 to 3.2. The variety called chiastolite contains carbonaceous inclusions in a regular crosslike arrangement.

The principal kinds of deposits of kyanite, sillimanite, and andalusite and their distinctive geologic features are as follows:

Deposits in quartzose rocks.—The Al_2SiO_5 and related minerals may be disseminated through the quartzose rock, or they may occur in irregular masses. The average content of the Al_2SiO_5 minerals is commonly over 15 percent. Other high-alumina minerals, such as alunite, chloritoid, corundum, diaspore, dumortierite, lazulite, pyrophyllite, staurolite, topaz, tourmaline, and white mica, may be present.

Deposits in metamorphosed argillaceous rocks.—The Al_2SiO_5 minerals are commonly disseminated through certain layers in some micaceous schists and gneisses. The average content of the Al_2SiO_5 minerals is generally under 15 percent.

Deposits in pegmatites and quartz veins.—These deposits are small and usually occur in schists and gneisses that carry the same Al_2SiO_5 minerals or related minerals.

Deposits in residual soils and placers.—The Al_2SiO_5 minerals may become concentrated in residual soils, stream placers, and beach sands.

The deposits in quartzose rocks and those in micaceous schist and gneiss are the largest and most important. The deposits range considerably in their size and content of the Al_2SiO_5 minerals. The quartzose deposits are generally smaller than the micaceous schist and gneiss deposits but are appreciably richer in the Al_2SiO_5 minerals; some quartzose deposits contain other high-alumina minerals also (see list above). Both in this country and abroad, the quartzose deposits have been more productive than the micaceous schist and gneiss deposits. The major domestic and foreign deposits of Al_2SiO_5 minerals in quartzose rocks and domestic deposits in micaceous schists and gneisses are listed in table 1.

TABLE 1.—*Major deposits of* Al_2SiO_5 *minerals*

Kyanite	Sillimanite	Andalusite
Deposits in quartzose rocks in the United States		
Farmville district, Virginia Kings Mountain district, North Carolina-South Carolina Graves Mountain, Ga. Hagers Mountain, N.C. Petaca district, N.Mex. Picuris Range, N.Mex. Ogilby, Calif.	Kings Mountain district, North Carolina-South Carolina Picuris Range, N.Mex.	Hillsboro, N.C. Boles Mountain, S.C. Hawthorne, Nev. White Mountain, Calif.
Foreign deposits in quartzose rocks		
Singhbhum district, India Murka-Loosoito district, Kenya Kapiridimba, Nyasaland Halfway Kop, Bechuanaland Yanmah, Australia Surinam	Sona Pahar, Assam, India Pipra, Rewa, India Mount Crawford (Williamstown), Australia Broken Hill, Australia Pela, Union of South Africa	Boliden district, Sweden Kounrad, U.S.S.R. Semis Bugu, U.S.S.R.

TABLE 1.—*Major deposits of* Al_2SiO_5 *minerals*—Continued

Kyanite	Sillimanite	Andalusite
Deposits in micaceous schists and gneisses in the United States		
Dutchess County, N.Y. Burnsville-Swannanoa district, North Carolina Habersham and Rabun Counties, Ga. Blue Ridge area, Georgia Iron County, Wis. Boehls Butte quadrangle, Idaho	Mount Monadnock, N.H. Dutchess County, N.Y. Southern Piedmont belt, North Carolina-South Carolina-Georgia Warne-Sylva belt, North Carolina Central Colorado (especially Holy Cross quadrangle) Southern Black Hills, S.D. Dillon, Mont. Troy, Idaho Boehls Butte quadrangle, Idaho	Littleton, Mass. Boehls Butte quadrangle, Idaho Piscataquis County, Maine

Deposits of much less importance are the pegmatites and quartz veins that contain kyanite, sillimanite, and andalusite, which are common in some areas of micaceous schist and gneiss in the Southeast. These deposits are small and are more noted as sources of fine mineral specimens than as minable ore deposits.

Kyanite, sillimanite, and andalusite are very resistant minerals; however, they may be liberated from the containing rock through weathering and become concentrated in some abundance in the soil. They are heavier than quartz, and accumulate along with the other heavy minerals in stream and beach placers. A few deposits of this nature are found in the region.

DEPOSITS IN QUARTZOSE ROCKS

The quartzose deposits of kyanite, sillimanite, and andalusite seem to be more varied and more numerous in the Southeast than in other parts of the country. The following classes of the quartzose group of deposits are found in the region:

- Kyanite-quartz deposits:
  - Foliated variety
  - Nonfoliated variety
- Sillimanite-quartz deposits
- Andalusite-pyrophyllite-quartz deposits

The different classes of deposits are similar in chemical composition, consisting principally of SiO_2 and Al_2O_3, but are somewhat different in their mineral content and other geologic features. The mineralogic and geologic characteristics of each class of quartzose deposits are described below. The major deposits and mineralogy of each class are summarized in table 2.

TABLE 2.—*Relative abundance of minerals in quartzose deposits of* Al_2SiO_5 *minerals in the Southeastern States*

[Explanation of symbols:
A, abundant (>10 percent) in all, or most deposits.
a, abundant (>10 percent) in only one, or a few deposits.
C, common (1 to 10 percent) in all, or most deposits.
c, common (1 to 10 percent) in only one, or a few deposits.
P, present (0.1 to 1 percent) in all, or most deposits.
p, present (0.1 to 1 percent) in only one, or a few deposits.
S, scarce (< 0.1 percent) in all, or most deposits.
s, scarce (< 0.1 percent) in only one, or a few deposits.
o, absent, or not known]

Minerals	Kyanite-quartz deposits, foliated variety[1]	Kyanite-quartz deposits, nonfoliated variety[2]	Sillimanite-quartz deposits[3]	Andalusite-pyrophyllite-quartz deposits[4]
Hypogene minerals				
Quartz	A	A	A	A
Aluminous minerals:				
Andalusite	p	s	c, P	A, c
Chloritoid	c	c	s	c
Corundum	s	o	s	s
Diaspore	s	s	S	c
Kyanite	A	A	p	c
Pyrophyllite	p	C	o	A
Sillimanite	s	s	A	o
Staurolite	c	o	o	s
Topaz	p	c	s	a
Tourmaline	s	p	s	s
Zunyite	o	s	o	o
Clay minerals:				
Unidentified clay mineral	c, S	s	S	p
Dickite	c, s	o	o	o
Kaolinite	s	o	o	o
Micas:				
White mica, unanalyzed	C	c	C	C
White mica, variety determined by analysis:				
Margarite	p	o	o	o
Muscovite	C	c	o	o
Paragonite	p	c	o	o
Phosphates:				
Crandallite	o	s	o	o
Goyazite	s	s	o	o
Lazulite	p	p	S	s
Variscite	s	o	o	o
Other minerals:				
Apatite	S	o	s	s
Barite	S	o	o	o
Gold	o	o	o	s
Magnetite	p	o	P	S
Pyrite	C, p	c	p	p
Rutile	P	P	P	P
Specular hematite	o	o	o	s
Sphalerite	s	o	o	o
Sphene	s	o	o	o
Spinel	s	o	o	o
Zircon	S	S	S	s

TABLE 2.—*Relative abundance of minerals in quartzose deposits of* Al_2SiO_5 *minerals in the Southeastern States*—Continued

Minerals	Kyanite-quartz deposits, foliated variety[1]	Kyanite-quartz deposits, nonfoliated variety[2]	Sillimanite-quartz deposits[3]	Andalusite-pyrophyllite-quartz deposits[4]
Supergene minerals				
Halloysite	c	o	o	o
Kaolinite	c	o	o	o
Limonite	C	c	S	p

[1] Farmville district and Halifax County, Va.; Kings Mountain district, North Carolina-South Carolina (except Clubb Mountain); Youngs Mountain, N.C.; Worth and Little Mountains, S.C.
[2] Hagers Mountain, Corbett deposit, and Clubb Mountain, N.C.; Graves Mountain, Ga.
[3] Reese Mountain, Machpelah Church, and Will Knox property, North Carolina; Ryan–Purcley property, South Carolina.
[4] Bowlings Mountain, Hillsboro, Snow Camp, and Staley, N.C.; Boles Mountain and Brewer topaz mine, South Carolina.

KYANITE-QUARTZ DEPOSITS

Kyanite-quartz deposits are the largest and most numerous of the group of high-alumina quartzose deposits in the Southeast; their distribution is shown on plate 1. The principal minerals are kyanite and quartz, which together generally make up at least 90 percent of the rock. Several percent of muscovite or other white mica is present in most deposits. Pyrite is a common mineral in many deposits as small grains disseminated through the rock; limonite occurs in such deposits as a weathering product of pyrite. Rutile is a widespread but minor constituent, generally being present in amounts ranging between 0.5 and 1 percent; it occurs as minute grains included in quartz and kyanite. Less common minerals are pyrophyllite, lazulite, topaz, and various minor accessories including several aluminum phosphates and clay minerals (table 2).

Two distinct varieties of kyanite-quartz rock—foliated and nonfoliated—are found in the region. All foliated deposits are elongated parallel to the foliation of the enclosing rock; some nonfoliated deposits are discordant to the foliation. Some deposits consist of a single lens or layer; others are composed of a group of lenticular bodies arranged in echelon. Individual bodies range in width from a few feet to several hundred feet and in length from less than a hundred feet to several miles. The most persistent and largest deposits are in the Farmville district, Virginia, and the Kings Mountain district, North Carolina–South Carolina. The deposits in these districts exhibit many characteristics of folded and metamorphosed sedimentary rocks. On the other hand, the kyanite-quartz deposits at Graves Mountain, Ga., and the Corbett property, North Carolina, have certain features suggestive of replacement deposits.

Kyanite-quartz rock is extremely resistant to weathering and erosion because of the relative insolubility of kyanite and quartz. The deposits characteristically form knobs or ridges; kyanite-quartz rock is well exposed in bold crags and cliffs in the largest deposits and in low ledges in the smaller ones. Willis and Crowders Mountains, The Pinnacle, and Graves Mountain are prominent monadnocks that rise several hundred feet above the general level of the surrounding country.

The surfaces of the exposures of kyanite-quartz rock are generally very rough and jagged, because the quartz grains are eroded more rapidly than the kyanite crystals, which remain as rough projections. In contrast, barren quartzose rock weathers to smooth rounded surfaces. Thus, the degree of roughness of the weathered surfaces in many deposits is an index of the kyanite content. The surfaces of some exposures of kyanite-quartz rock are marked with pits, furrows, and irregular cavities resulting from the differential erosion of kyanite and quartz. Many cavities open downward and appear to have been developed and enlarged by the loosening and dropping out of grains of kyanite and quartz along small folds, foliation, bedding, and joint planes.

PETROGRAPHY AND CHEMISTRY

The kyanite-quartz rock commonly contains at least 90 percent combined Al_2O_3 and SiO_2. Chemical and spectrochemical analyses of kyanite quartzite[1] from the Farmville district, Virginia, and the Kings Mountain district, North Carolina–South Carolina, are given in table 3.

Quartz is the most abundant mineral in the kyanite-quartz deposits, generally making up 60 to 80 percent of the rock. In the nonfoliated varieties, quartz is typically very fine grained and forms a mosaic texture of unstrained grains (fig. 1). Quartz in foliated kyanite-quartz rock may be fine grained (fig. 2) or coarsely crystalline and strained (fig. 3).

Kyanite generally constitutes 10 to 30 percent of the rock. It is most commonly white to light gray but is blue in several deposits. The mineral occurs in a wide variety of ways. In strongly foliated kyanite-quartz rock, the kyanite crystals are commonly segregated in layers of parallel crystals that are a centimeter or so long. Quartz inclusions may be present in kyanite in the fine-grained rock (fig. 2)

[1] The terms "kyanite quartzite" and "sillimanite quartzite" are used in this report only for metamorphic rocks that probably were argillaceous sandstones originally. "Kyanite-quartz rock" is the name applied to metamorphic rocks that are either of probable nonsedimentary origin or of unknown origin; it is also used as a general term for all rocks composed principally of these two minerals.

TABLE 3.—*Chemical and spectrochemical analyses of kyanite quartzite and sillimanite quartzite from Farmville district, Virginia, and Kings Mountain district, North Carolina-South Carolina*

	Kyanite quartzite			Sillimanite quartzite	
	VB-W	SY-87	NG-437	NG-439	NG-440
Chemical analyses [VB-W: L. D. Trumbull, analyst; SY-87, NG-437, NG-439, NG-440: L. N. Tarrant, analyst]					
SiO_2	68.71	73.56	63.35	75.33	69.59
Al_2O_3	27.61	17.01	28.97	23.36	27.24
Fe_2O_3	.57	.00	2.25	.04	.17
FeO	.04	5.25	2.50	.18	.13
MgO	.14	.01	.31	.01	.01
CaO	.41	.00	.07	.01	.17
Na_2O	.00	.00	.13	.02	.00
K_2O	.14	.00	.04	.10	.00
H_2O-	.04	.01	.05	.02	.01
H_2O+	.32	.12	1.30	.19	.58
TiO_2	1.02	.48	.86	.60	1.46
CO_2	.02	.01	.01	.02	.02
P_2O_5	.32	.11	.09	.06	.33
F	.21	....	....	....	....
S	....	4.62	....	....	.03
MnO	.00	.00	.05	.00 (Tr.)	.00 (Tr.)
Total	99.55	101.18	....	....	99.74
Less O for F	.09	....	....	....	....
Less O for S	....	1.16	....	....	.01
Total	99.46	100.02	99.98	99.94	99.73

Spectrochemical analyses

[P. R. Barnett, analyst. Zeros in unit column signify that the elements were not detected; sensitivity limits for these elements are: B, 0.003; Be, 0.0001; Co, 0.0005; Ga, 0.0005; La, 0.005; Mo, 0.0001; Ni, 0.0003; Pb, 0.0006; Sn, 0.001; Sr, 0.0008; Y, 0.001; Yb, 0.0001; Zn, 0.01. Elements not detected in any of these samples, together with their sensitivity limits, are: Ag, 0.0005; As, 0.05; Au, 0.003; Bi, 0.001; Cd, 0.005; Ge, 0.0005; In, 0.001; Nb, 0.001; Pt, 0.003; Sb, 0.01; Ta, 0.05; Th, 0.05; Tl, 0.01; U, 0.05; W, 0.01]

	VB-W	SY-87	NG-437	NG-439	NG-440
B	0	0	.04	0	.003
Ba	.02	.04	.0004	.0006	.08
Be	0	0	0	0	.0001
Co	0	.001	0	0	0
Cr	.002	.0004	.006	.0008	.01
Cu	.001	.0009	.001	.0006	.0007
Ga	0	.0005	.002	.0006	.003
La	0	.008	0	0	.01
Mo	.002	.0007	0	0	.0004
Ni	0	.0003	.0003	0	.0003
Pb	.001	0	.001	0	.0006
Sc	.0001	.0004	.002	.0001	.0009
Sn	.002	0	0	.003	0
Sr	.4	.09	.0008	0	.5
V	.1	.009	.06	.006	.03
Y	.002	.002	.002	0	.002
Yb	0	.0003	.0002	0	.0001
Zn	0	0	.03	0	0
Zr	.01	.01	.01	.02	.02

Content of principal minerals, as calculated from chemical analyses

	VB-W	SY-87	NG-439	NG-440
Quartz	52.6	63.3	61.9	53.8
Kyanite [1]	43.7	27.0	....	....
Sillimanite	....	....	37.0	....
Sillimanite and andalusite	....	....	....	43.1
Rutile	1.02	.48	.60	1.46
Pyrite	....	8.66	....	....
Total	97.32	99.44	99.5	98.36

[1] Includes about 4 percent topaz, as determined by point-counter method of analysis of 6 thin sections.

Mode

	NG-437		NG-437
Quartz	40	Magnetite	3
Kyanite	40	Andalusite, rutile, staurolite, and zircon	Minor
Chloritoid	17	Total	100

Location of samples:

VB-W, Lab. No. 53-835SCD. Composite sample of kyanite quartzite from 6 pieces of diamond-drill core from 5 drill holes, Willis Mountain, Buckingham County, Va.

SY-87, Lab. No. 52-1611CDSW. Composite sample of kyanite quartzite taken from 6 places in northern opencut of Commercialores, Inc., Henry Knob, York County, S.C.

NG-437, Lab. No. 52-1605CDSW. Composite sample of 6 pieces of kyanite-chloritoid quartzite taken across strike of 10-foot bed, 1.2 miles S. 10° W. of Crowders Mountain Village, Gaston County, N.C.

NG-439, Lab. No. 52-1607CDSW. Composite sample of 6 pieces of sillimanite quartzite from crest of Reese Mountain, Lincoln County, N.C.

NG-440, Lab. No. 52-1608CDSW. Composite sample of 6 pieces of sillimanite quartzite from Will Knox property, Gaston County, N.C.

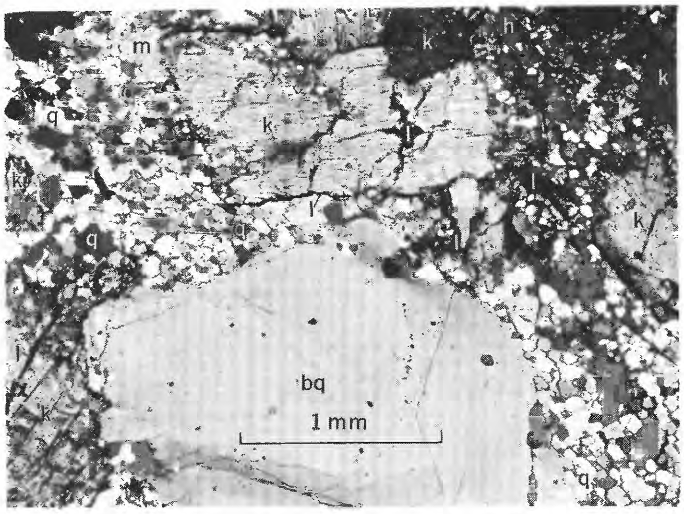


FIGURE 1.—Photomicrograph of kyanite-quartz rock from Graves Mountain, Lincoln County, Ga. Shows kyanite (k), fine-grained quartz (q), relict phenocryst of blue (bq), a little muscovite(?) (m), and rutile (r). Rock is highly weathered and contains much limonite (l). Holes in section (h). Crossed nicols.

and absent in coarse-grained foliated rock (fig. 3). In some gneissic kyanite-quartz rock the layers of kyanite are less uniform, and the crystals are not so well oriented (fig. 4). In the occurrences just

FIGURE 2.—Photomicrograph of kyanite quartzite from crest of Crowders Mountain, Gaston County, N.C. Shows typical anhedral habit of much of the kyanite (k) in the district. Opaque mineral is pyrite. Other minerals are quartz (q) and limonite-stained white mica (m). Plane-polarized light.

TABLE 4.—*Micas from Southeastern kyanite-quartz deposits*

[Analysts: H. S. Yoder, Jr., Geophysical Laboratory, Carnegie Institution of Washington; all others, U.S. Geological Survey]

Type of mica	Specimen No.	Locality	Characteristics	Percent		Other constituents determined	X-ray determination [1]	Optical properties [By D. H. Richter]				Remarks
				K_2O	Na_2O			Nα	Nβ	Nγ	(−)2V	
Muscovite	VB-W19-22	Drill hole 19 at 22 ft, Willis Mountain, Buckingham County, Va.	Coarse white mica in kyanite-quartz-mica schist.	7.22	2.44	.....	.....	.....	1.587	1.595	45°	Chemical analysis by J. M. Dowd.
Do	VB-115	Willis River, Buckingham County, Va., about 1 mile west of U.S. Highway 15 bridge across river.	Soft dense white mineral replacing kyanite in micaceous kyanite quartzite.	.....	.....	.....	Principally muscovite, minor kaolinite, possibly some quartz; film No. 9441. By D. H. Richter.	.....	.....	.....	.....	Compare with VB-116, same locality.
Do	NP-15	Hagers Mountain, Person County, N.C.	Irregular aggregates of fine-grained tan to flesh-colored poorly micaceous mineral in fine-grained quartz.	8.33	1.90	.....	.....	1.570	1.593	1.599	36°	Compare with NP-24, same locality. Chemical analyses by L. M. Kehl.
Do	SN-5	Little Mountain, Newberry County, S.C.	Coarse white to pale-green mica interstitial to light greenish-blue kyanite crystals.	9.87	.64	.....	Muscovite; film No. 6244. By J. M. Axelrod.	.....	.....	.....	.....	Chemical analysis by E. A. Nygaard.
Chromian muscovite.	VC-27b	0.3 mile west of junction of Highways 47 and 649, Madisonville, Charlotte County, Va.	Soft dense green mineral replacing bluish-green kyanite. Mica has fibrous habit under microscope.	8.25	1.35	Little chromium.	Muscovite; film No. 6878. By F. A. Hildebrand.	1.568 to 1.570	1.598 to 1.609		.....	Chemical analysis by J. M. Dowd.
Do	VPE-101	Kyanite Mining Corp. mine, Baker Mountain, Prince Edward County, Va.	Coarse bright green mica replacing (?) blue kyanite in kyanite-quartz-mica schist.	7.95	1.53	do	Muscovite; structure identical with VC-27b; film No. 6879. By F. A. Hildebrand.	.....	1.594	1.599	40°	Do.
Do	SY-2a	South end of ridge that lies about half a mile west of Nanny Mountain, York County, S.C.	Soft dense bright green mineral.	.....	.....	do	Muscovite; film No. 9376. By D. H. Richter.	.....	[3]1.590	[3]1.597	40°	
Paragonite	NP-24	Same locality as NP-15.	Soft dense light-tan mineral with waxy luster, replacing kyanite.	3.05	5.10	.....	Paragonite; film No. 6243. By J. M. Axelrod.	1.572	1.595	1.602	38°	Compare with NP-15, same locality. Chemical analysis by L. M. Kehl.
Do	SA-2	Road on west side of Parsons Mountain, Abbeville County, S.C.	Soft white fibrous mineral forming felty masses in quartz-mica schist.	.....	.....	.....	Paragonite, quartz; film No. 7038. By F. A. Hildebrand.	.....	.....	.....	.....	
Two distinct varieties:	VB-116	Same locality as VB-115.	Soft dense light-gray mineral with waxy luster in granulated vein quartz. Two fairly distinct types of mica were observed and separated under binocular miscroscope by D. H. Richter.	.....	.....	.....	.....	.....	.....	.....	.....	Compare with VB-115, same locality.

Parag-onite.	VB-116a...	VB-116a: Typical colorless mica with good micaceous cleavage.	1.48	5.22	0.0X percent Li.	Paragonite; film No. 6880. By F. A. Hildebrand.[4]		[3]1.604	[3]1.604	0-5°	Chemical analyses by J. M. Dowd and J. D. Fletcher.
			2.1	5.6	1.6 percent Ca.	Paragonite plus muscovite and minor kaolinite. By H. S. Yoder, Jr.					Chemical analyses by P. L. Elmore.
Marga-rite.	VB-116b...	VB-116b: Colorless bundles of fibers and poorly defined plates with a slight waxy luster.	.79	4.9	4.9 percent Ca; 0.X percent Li.	Margarite. By H. S. Yoder, Jr.	1.595	1.613	1.618	325°	Chemical analyses by P. L. Elmore and J. D. Fletcher.

1 X-ray powder camera method used by D. H. Richter, F. A. Hildebrand, and J. M. Axelrod. X-ray diffractometer method used by H. S. Yoder, Jr.
2 See complete chemical analysis in table 5.
3 Approximate.
4 The absence of muscovite and kaolinite in this material suggests that it was not identical with material analyzed by H. S. Yoder, Jr.

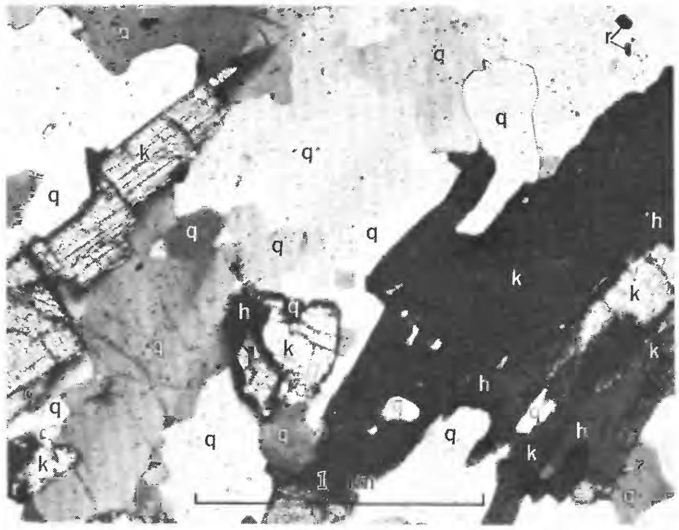


FIGURE 3.—Photomicrograph of kyanite quartzite from Baker Mountain, Prince Edward County, Va. Shows well-developed bladed kyanite crystals (k) and coarsely crystalline quartz (q) in characteristic gneissic structure. Rutile (r); holes in section (h). Crossed nicols.

described, kyanite is distributed rather uniformly through the rock. Aggregates of nearly pure kyanite, generally only a few inches across, are found in some deposits. Kyanite may form coarse-tufted aggregates of radiating crystals conformable to the foliation (fig. 5), clusters of randomly oriented kyanite crystals a few inches across (fig. 6), or lenses of massive kyanite many feet in length. The principal occurrence of lenses of massive kyanite is in strongly foliated kyanite quartzite at Willis Mountain (fig. 7). In nonfoliated kyanite-quartz rock, kyanite may occur in irregular stringers forming a network in the rock, or it may form irregular aggregates. Kyanite crystals in nonfoliated kyanite-quartz rock are unoriented and some contain abundant quartz inclusions (fig. 8).

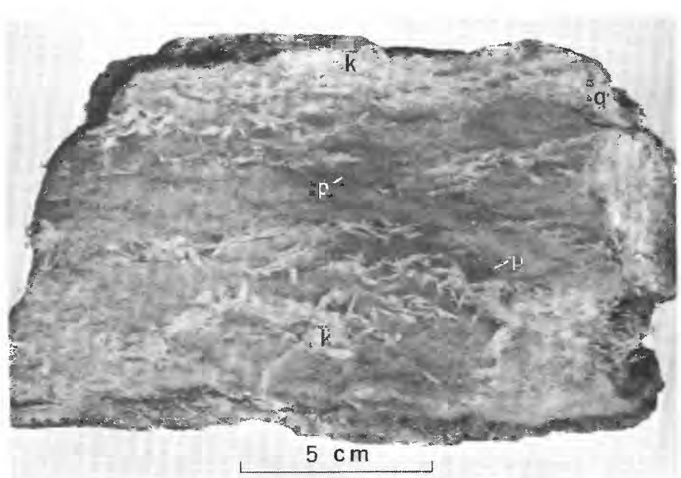


FIGURE 4.—Kyanite quartzite (polished surface) from Henry Knob, York County, S.C. Shows kyanite (k), pyrite (p), quartz (q).

White mica is very common in the kyanite-quartz deposits. It is probably the potassium mica, muscovite, in most localities, but the sodium mica, paragonite, has been identified in several deposits, and the calcium mica, margarite, at one locality

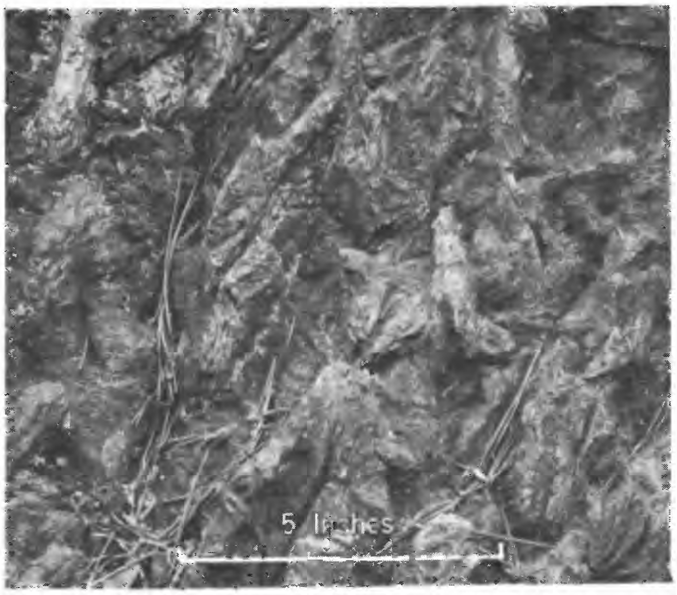


FIGURE 5.—Coarse-tufted aggregates of kyanite lying in plane of foliation of quartzite, Shelton property, Gaston County, N.C. Photograph by W. C. Overstreet.

(table 4). Recognition of the sodium and calcium micas followed the discovery of paragonite in kyanite-quartz rock at Hagers Mountain, N.C. A soft waxy light-tan mineral here was first thought to be pyrophyllite, but the abrasion pH test of Stevens and

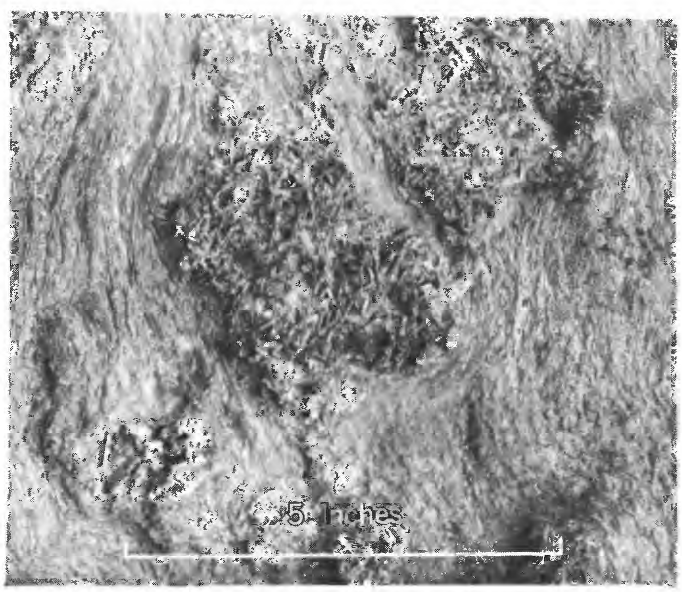


FIGURE 6.—Coarse-grained aggregates of platy blue kyanite in quartzite, north end of Clubb Mountain, Lincoln County, N.C. Foliated groundmass consists of quartz and limonite-stained white mica. Photograph by W. C. Overstreet.

FIGURE 7.—Massive kyanite from Willis Mountain, Buckingham County, Va. Composed of intergrowths of radiating kyanite (k) crystals, some muscovite (m), and minor amounts of pyrite (p) and rutile (r).

Carron (1948) gave a strong alkaline reaction; subsequent X-ray and chemical analyses established the mineral to be paragonite (specimen NP–24, table 4). Similar soft dense minerals from other localities that gave alkaline reaction with the pH abrasion test were studied microscopically by D. H. Ritcher; chemical and X-ray analyses were made by other workers. Paragonite was found in speci-

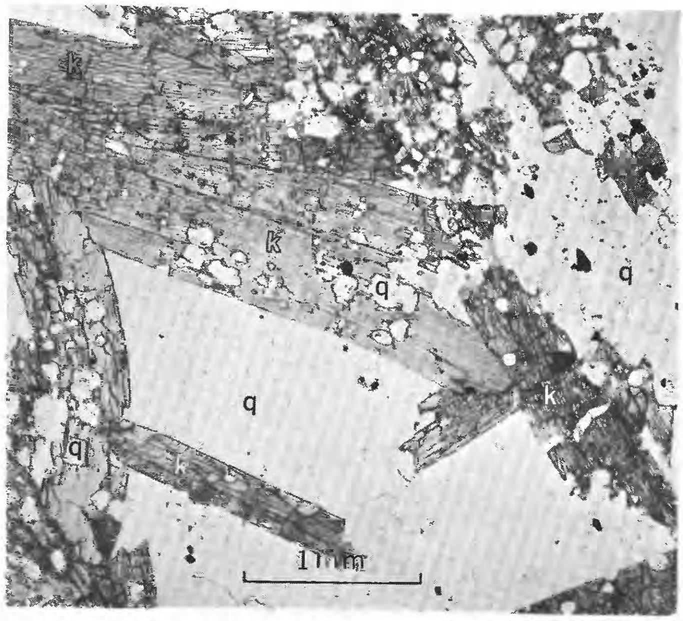


FIGURE 8.—Photomicrograph of kyanite quartzite from outcrop on Clubb Mountain, 1,800 feet north of Gaston County line, Lincoln County. N.C. Shows typical poikiloblastic habit of much kyanite (k) in district. Opaque mineral is pyrite. Inclusions and groundmass are quartz (q). Plane-polarized light.

mens from 2 other localities (SA–2 and VB–116a, table 4), but the fine-grained mica from 4 localities was identified as muscovite (VB–115, NP–15, VC–27b, and SY–2a, table 4), and as margarite from 1 locality (VB–116b, table 4). It is interesting that fine-grained paragonite (NP–24) and muscovite (NP–15) both occur at Hagers Mountain, and fine-grained muscovite (VB–115), paragonite (VB–116a), and margarite (VB–116b) all occur at the same locality on Willis River in Buckingham County, Va. Chemical analyses of the two fine-grained micas at Hagers Mountain are given in table 5. Three samples of flake mica all proved to be muscovite (VB–W19–22, SN–5, VPE–101). Samples of green mica from three localities, both coarse- (VPE–101) and fine-grained (VC–27b and SY–2a), were determined as chromian varieties of muscovite. Dietrich (1956) describes paragonite from kyanite veins at a locality in Campbell County, Va., and another in Franklin County, Va.

Fine-grained micas replace kyanite at several localities (figs. 9, 10, 11). Formation of these fine-grained micas probably took place in the declining stages of metamorphism.

TABLE 5.—*Chemical analyses of paragonite and muscovite from Hagers Mountain, Person County, N.C.*

[Lucille M. Kehl, analyst]

	Paragonite (NP–24) (Lab. No. 52–1678CDMW)	Muscovite (NP–15) (Lab. No. 52–1679CDMW)
SiO_2	46.78	46.55
Al_2O_3	38.99	36.97
Fe_2O_3	.44	.74
FeO	.01	.10
MgO	.00	.15
CaO	.12	.00
Na_2O	5.10	1.90
K_2O	3.05	8.33
H_2O-	.14	.06
H_2O+	4.80	4.28
TiO_2	.11	.36
CO_2	.01	.04
P_2O_5	.09	.06
F	.05	.06
MnO	.00	.00
BaO	.07	.19
Total	99.76	99.79
Less O for F	.02	.03
Total	99.74	99.76

Samples were prepared for chemical analysis by Donald H. Richter, who also determined the following optical properties:

N_α	1.572	1.570
N_β	1.595	1.593
N_γ	1.602	1.599
(–) 2V	38°	36°
$N_\gamma - N_\alpha$	.030	.029

Hydrothermal clay minerals occur in some abundance in kyanite quartzite in parts of the Crowders Mountain and Clubb Mountain deposits and in minor amounts at Willis Mountain and several other deposits. The clay mineral at Crowders Mountain is dickite;[2] both dickite and kaolinite occur at Willis Mountain.[3] The clay minerals vein and replace both kyanite and quartz (fig. 11). Dickite replaces diaspore and kyanite at Willis Mountain (fig. 12).

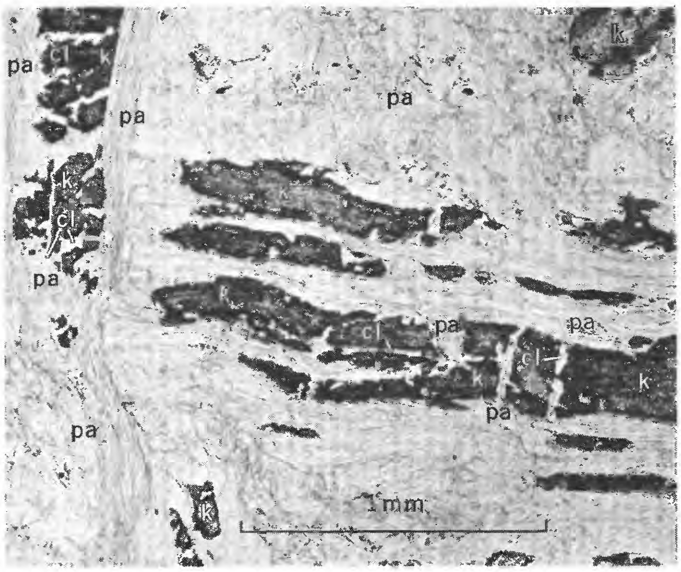


FIGURE 9.—Photomicrograph of kyanite-paragonite rock from Hagers Mountain, Person County, N.C. Shows kyanite (k) veined and partly replaced by fine-grained paragonite (pa) and minor amount of clay mineral (cl). Plane-polarized light.

Pyrophyllite is most abundant in the nonfoliated kyanite-quartz deposits. It is common in veins and masses of radiating crystals at two of the nonfoliated deposits (Corbett deposit, North Carolina, and Graves Mountain, Ga.), and also in the southern part of the foliated deposit at Clubb Mountain, N.C. Pyrophyllite seems to replace kyanite and quartz in the same manner as the clay minerals and the fine-grained micas do.

Fine grains of topaz occur locally in very small amounts in several of the foliated deposits. It is rather abundant in parts of the nonfoliated deposit at the Corbett property (fig. 13).

The iron-aluminum phosphate lazulite, is common as large dark-blue crystals with pyrophyllite and quartz at Clubb Mountain and with kyanite at Graves Mountain, two well-known localities for this mineral. Other aluminum phosphate minerals found in minor amounts are the strontium-aluminum phos-

[2] Identified by R. L. Smith.
[3] Identified by X-ray determination by F. A. Hildebrand and electron microscopy by C. P. Davis and E. J. Dwornik.

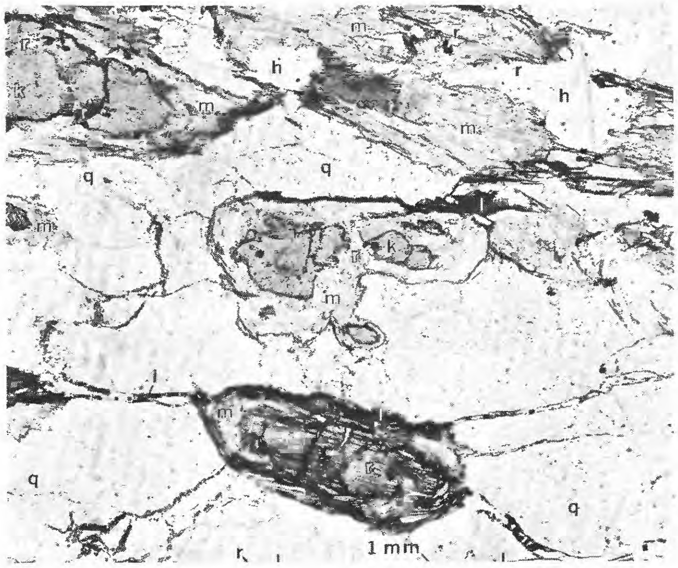


FIGURE 10.—Photomicrograph of kyanite quartzite, from about 0.3 mile west of Madisonville, Charlotte County, Va. Shows characteristic gneissic structure, with kyanite (k) partly replaced by finely fibrous chromian muscovite (m.); quartz (q), rutile (r), limonite (l), holes in section (h). Plane-polarized light.

phate goyazite, at Clubb and Crowders Mountains; the calcium-aluminum phosphate crandallite, at Clubb Mountain; and the aluminum phosphate variscite found in one thin stringer in drill core from Willis Mountain.

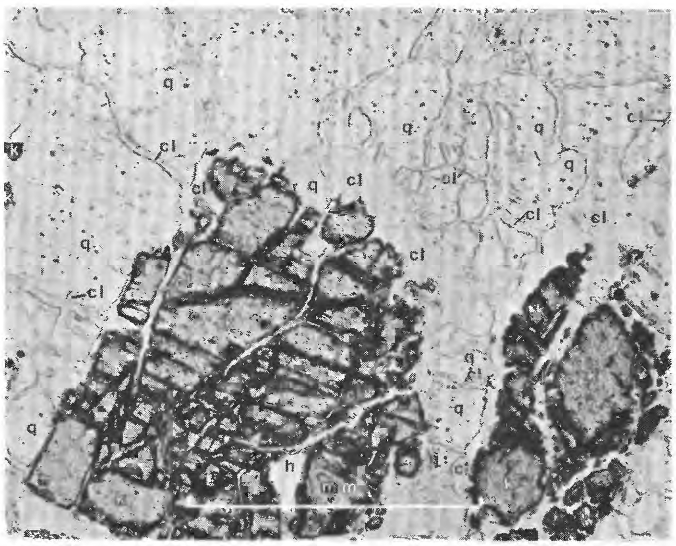


FIGURE 11.—Photomicrograph of kyanite quartzite cut by clay veinlets, from diamond-drill hole 6 (at 116 ft), Willis Mountain, Buckingham County, Va. Shows kyanite (k), and quartz (q) veined by clay mineral (cl). Rutile (r). Two types of clay have been identified in specimen by X-ray and electron microscope: (1) dickite and (2) kaolinite and (or) hallosyite. Holes in section (h). Plane-polarized light.

Other aluminous minerals in kyanite-quartz rock (found in moderate amounts in several deposits in the Kings Mountain district) are chloritoid (fig. 14), staurolite, and andalusite. Aluminous minerals of very rare occurrence are corundum, diaspore (fig. 12), sillimanite, and zunyite. Other accessory minerals are listed in table 2.

SILLIMANITE-QUARTZ DEPOSITS

Deposits of sillimanite-quartz rock have been found only in the Kings Mountain district, North Carolina–South Carolina. Their structure and petrography are discussed but briefly here, because they are described more fully in the section on the Kings Mountain district.

The sillimanite quartzite deposits are relatively small; most of them are between 10 and 30 feet

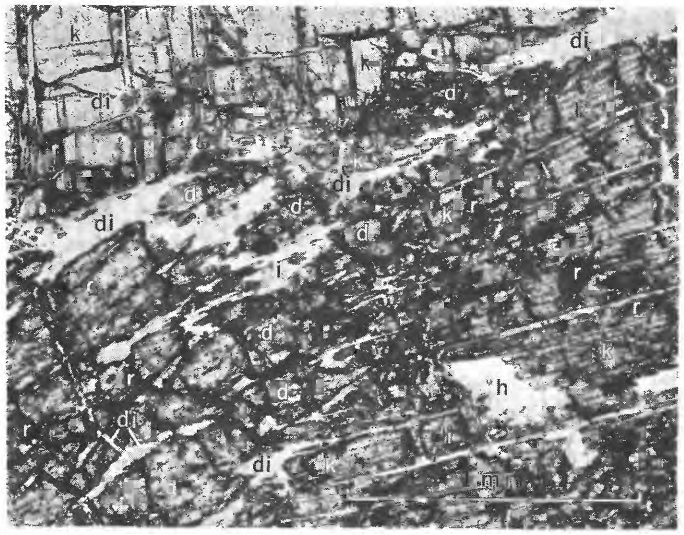


FIGURE 12.—Photomicrograph of kyanite (k) and diaspore (d) veined by dickite (di), Willis Mountain, Buckingham County, Va. Rutile (r); hole in section (h). Plane-polarized light.

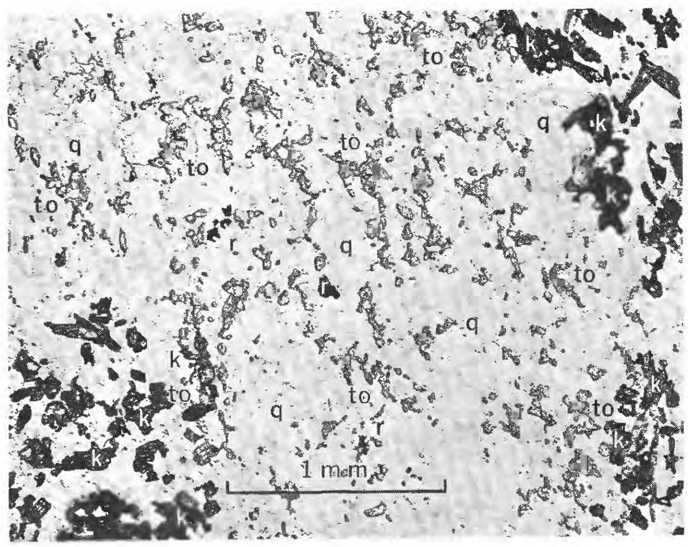


FIGURE 13.—Photomicrograph of topaz (to) and kyanite (k) in fine-grained quartz (q), from Corbett deposit, about 5 miles west of Smithfield, Johnston County, N.C. Rutile (r). Specimen contains about 70 percent quartz, 20 percent topaz, and 10 percent kyanite. Plane-polarized light.

thick and a few hundred yards long. Several parallel layers usually occur together. Most of the deposits form low knobs or hills, and the sillimanite quartzite is exposed in ledges a few feet high. The sillimanite typically weathers bone white in contrast to the glassy luster of the quartz. Barren coarse-grained quartzite and white mica schist occur with nearly all the deposits. The sillimanite quartzite deposits in the Kings Mountain district are all less than 1 mile from a large body of quartz monzonite.

FIGURE 14.—Photomicrograph of kyanite-chloritoid quartzite from locality 1.2 miles S. 10° W. of Crowders Mountain village, Gaston County, N.C. Shows typical fine-grained quartz (q), radial aggregates of chloritoid (ch), and kyanite (k). Crossed nicols.

Quartz and sillimanite are the principal minerals. Sillimanite typically occurs in matted aggregates and bundles of very fine fibrous crystals (fig. 15); coarse prismatic crystals are also present in places. The sillimanite content is generally between 10 and 35 percent. Andalusite is an abundant mineral in parts of the deposit on the Will Knox property (fig. 16). Kyanite also occurs in this deposit, but is less abundant than sillimanite or andalusite. All 3 of the Al_2SiO_5 minerals are present in 7 thin sections from various sillimanite quartzite deposits. Other aluminous minerals that are found locally in amounts of a few percent or more are white mica, diaspore, topaz, and lazulite. Rutile is a widespread accessory mineral in sillimanite quartzite; other accessory minerals are listed in table 2. Chemical, spectrochemical, and calculated mineral content of sillimanite quartzite from two deposits in the Kings Mountain district are given in table 3.

ANDALUSITE-PYROPHYLLITE-QUARTZ DEPOSITS

Significant amounts of andalusite and other high-alumina minerals were recently discovered in some

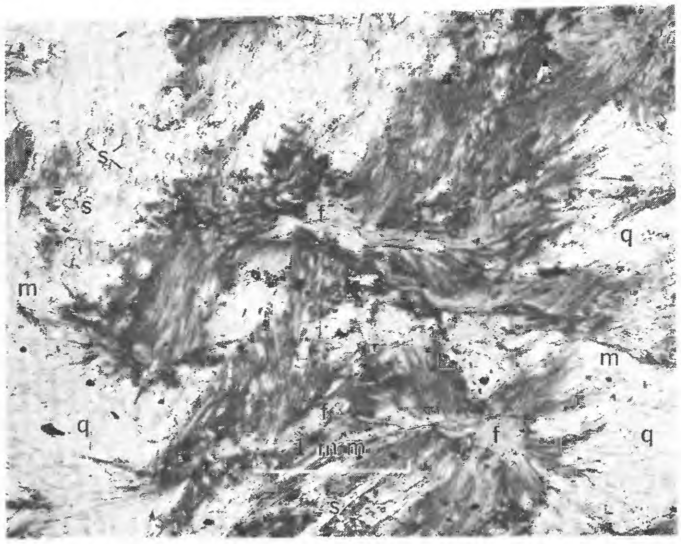


FIGURE 15.—Photomicrograph of sillimanite quartzite from Ryan-Purcley property, Gaston County, N.C. Shows typical mats of fibrous sillimanite (f), coarser prisms of sillimanite (s), coarse white mica (m), and quartz (q) groundmass. Small dark grains are rutile. Note way in which fibrous sillimanite fingers out into quartz groundmass. Plane-polarized light.

of the North Carolina pyrophyllite deposits by Broadhurst and Councill (1953) and at Boles Mountain, S.C. by us. These deposits are lenticular bodies of various shapes and sizes in sericite schist and silicified zones in silicic volcanic rocks. The deposits all lie in the Piedmont belt of volcanic rocks and slates (pl. 1). Their shapes and structures are not well known because none of them has been mapped in detail. Stuckey (1928, p. 35–37) has concluded that these deposits were formed by the replacement

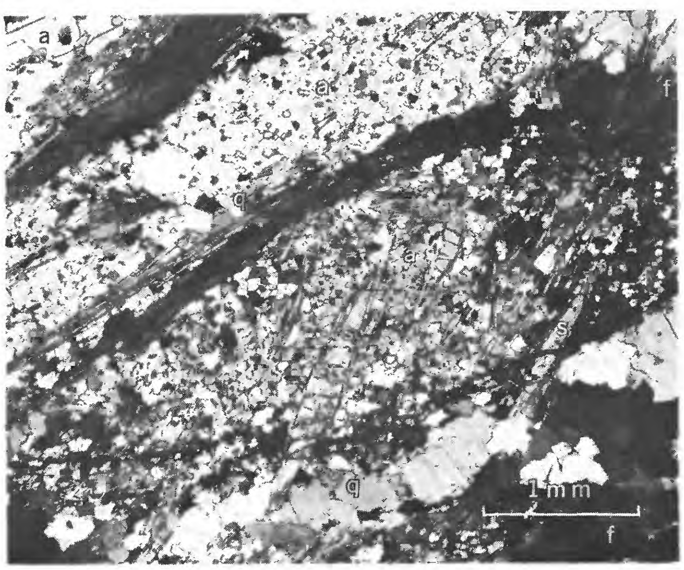


FIGURE 16.—Photomicrograph of andalusite-sillimanite quartzite from Will Knox property, Gaston County, N. C. Shows coarse anhedral andalusite (a) with numerous quartz inclusions, coarse prisms of sillimanite (s) penetrating andalusite, fibrous sillimanite (f), and inequigranular quartz (q) groundmass. Crossed nicols.

of tuffs and breccias of dacitic and rhyolitic composition. His principal points of evidence are the preservation of primary features (bedding and breccia structure) in the mineralized rocks and the presence of isolated masses of unaltered or only partly altered country rock in some deposits.

Andalusite generally occurs as light-gray to bluish grains in a matrix of pyrophyllite and very fine grained quartz. Both andalusite and quartz are replaced by pyrophyllite (fig. 17). Diaspore is commonly present in minor to moderate amounts. Stringers and aggregates of diaspore seem to be associated with the pyrophyllite replacement in some localities (figs. 17, 18, 20); in one deposit, diaspore and andalusite are intergrown, and both are veined by pyrophyllite (fig. 19). A clay mineral, with optical properties similar to those of kaolinite, is present in very small amounts in some deposits (figs. 17, 18). Small amounts of kyanite (fig. 18), topaz, corundum, and lazulite occur locally in some deposits. Fine-grained topaz resembling chert in the hand specimen and having a cryptocrystalline texture is found in parts of the deposit at Bowlings Mountain, N.C. Topaz of identical character was first discovered at the Brewer gold mine, Chesterfield County, S.C. (Pardee, and others, 1937), where it occurs in veins and irregular masses in dense siliceous rock; pyrophyllite, andalusite, and kyanite are also present in the Brewer deposit. Rutile in fine grains is a constant accessory in these deposits; other accessory minerals are listed in table 2.

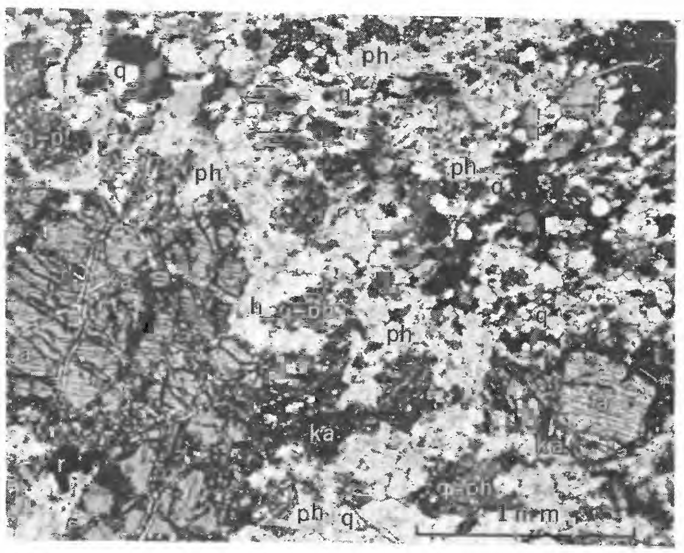


FIGURE 17.—Photomicrograph of andalusite-pyrophyllite-quartz rock from Carolina Pyrophyllite Co. mine, Bowlings Mountain, Granville County, N.C. Shows fine-grained quartz (q) partly replaced by pyrophyllite (ph); some quartz grains containing numerous small pyrophyllite flakes (q-ph); andalusite (a), veined and partly replaced by clay mineral, probably kaolinite (ka), with narrow stringers of diaspore (d) in center of some clay veinlets; rutile (r). Crossed nicols.

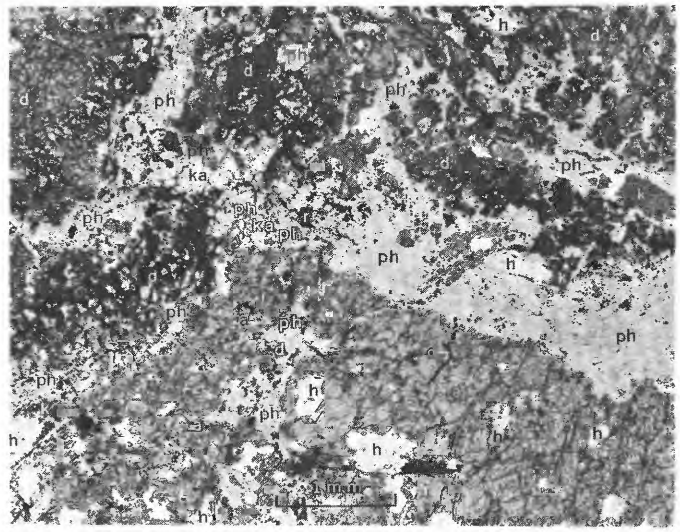


FIGURE 18.—Photomicrograph of andalusite-diaspore-pyrophyllite rock from Boles Mountain, Edgefield County, S.C. Shows andalusite (a) partly replaced by pyrophyllite (ph); fine to coarse grains of diaspore (d) in pyrophyllite; several kyanite crystals (k), rutile grains (r), and patchy areas of clay mineral, probably kaolinite (ka). Holes in section (h). Plane-polarized light.

DEPOSITS IN MICACEOUS SCHISTS AND GNEISSES

KYANITE SCHIST AND GNEISS

Kyanite is a rather abundant constituent of schist or gneiss in certain areas of the Blue Ridge of western North Carolina and northern Georgia. Less important deposits of kyanite schist are also known

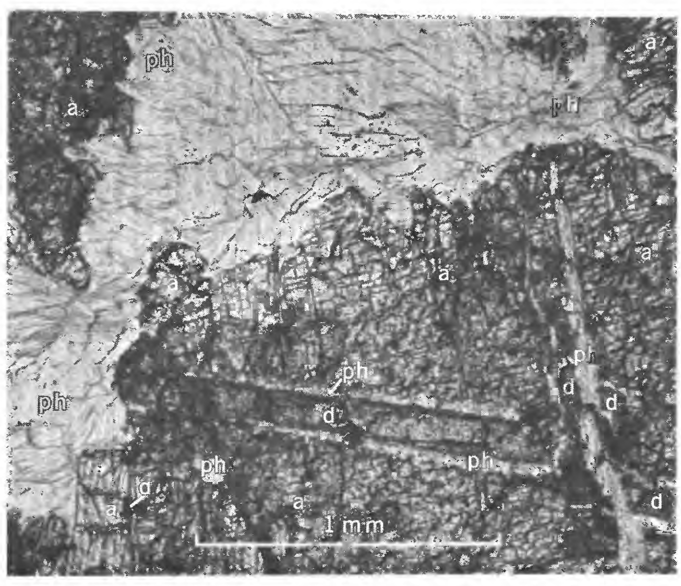


FIGURE 19.—Photomicrograph of andalusite-diaspore-pyrophyllite rock from North State Pyrophyllite Co. prospect, Hillsboro, Orange County, N.C. Shows andalusite (a) and diaspore (d) in matrix of pyrophyllite (ph). Minor veining of andalusite and diaspore by pyrophyllite. Plane-polarized light.

at some places in the Piedmont of Virginia, North Carolina, and Georgia.

Muscovite, quartz, and kyanite are the dominant minerals in kyanite schist; biotite, garnet, and graphite are commonly present too, and staurolite and tourmaline are found in some areas. Sodic oligoclase is an abundant mineral in the garnetiferous kyanite gneiss of the Burnsville-Swannanoa area, North Carolina (fig. 20). The kyanite

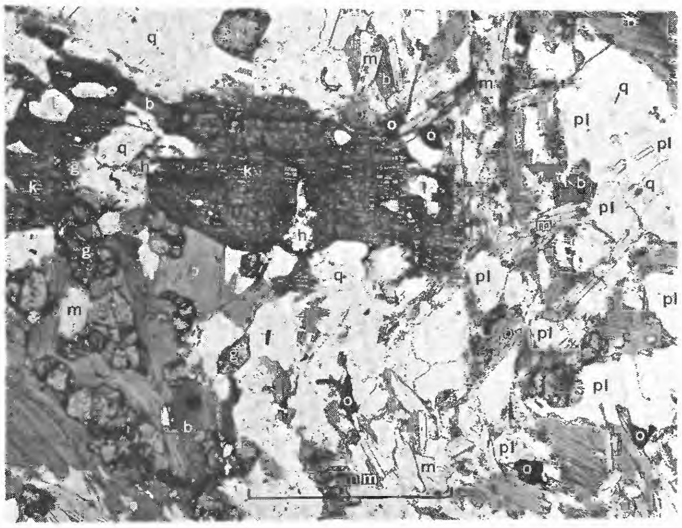


FIGURE 20.—Photomicrograph of kyanite-bearing gneiss from Yancey Cyanite Co. mine, Celo Mountain, Yancey County, N.C. Shows kyanite (k), garnet (g), biotite (b), muscovite (m), quartz (q), and plagioclase (pl). Black areas of opaque mineral (o) are magnetite and pyrrhotite. Holes in section (h). Plane-polarized light.

crystals are commonly blue. They have a wide range in size at different localities, from about an eighth of an inch to several inches in length. Layers of schist or gneiss in which kyanite is rather evenly distributed commonly alternate with layers that contain little or no kyanite. Some quartz veins or pegmatites carry kyanite. The kyanite content of zones that are 100 feet or so thick ranges from a few percent to about 10 percent; individual layers contain 15 percent or more of kyanite.

SILLIMANITE SCHIST AND GNEISS

Sillimanite schist has recently been found widespread in the region, particularly in a belt in the western Piedmont that extends from North Carolina to eastern Georgia and in another belt in the Blue Ridge of western North Carolina and northern Georgia.

Sillimanite typically occurs in quartz-mica schist, in which biotite is generally much more abundant than muscovite; feldspar is absent from much of the rock, though orthoclase is found in places. Other minerals commonly present are garnet, staurolite,

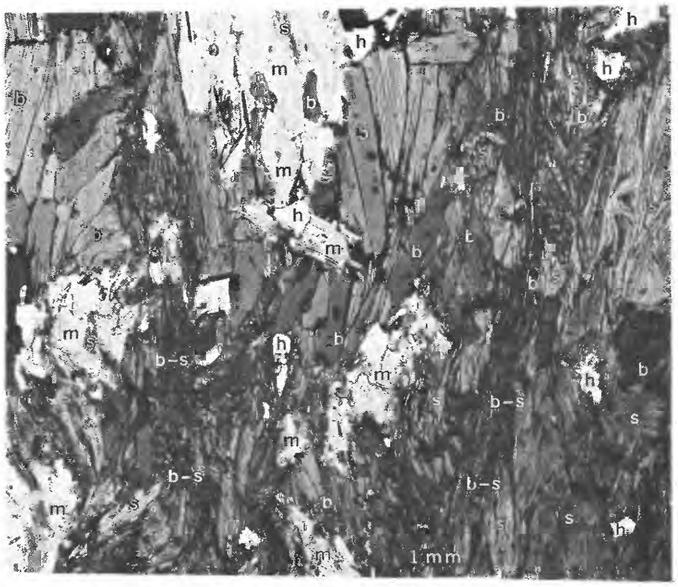


FIGURE 21.—Photomicrograph of sillimanite-biotite-muscovite schist from Cages Mountain, Caldwell County, N.C. Shows biotite (b) and muscovite (m) intergrown with fine fibrous sillimanite (s); in some areas biotite and sillimanite are very intimately mixed (b-s). Holes in section (h). Plane-polarized light.

chlorite, magnetite(?), pyrite, ilmenite, and tourmaline. A little kyanite accompanies the sillimanite at some localities. Sillimanite occurs most commonly as clusters of fine fibrous crystals closely intergrown with mica (fig. 21); it also forms coarse prismatic crystals in some deposits (fig. 22). Sillimanite may be concentrated in certain layers distributed rather uniformly through the rock. Sil-

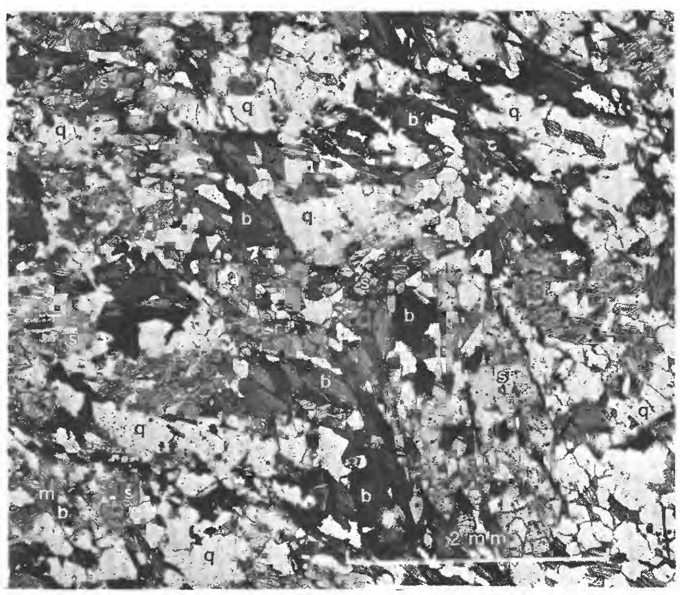


FIGURE 22.—Photomicrograph of sillimanite-biotite-quartz schist from Gideon property, about 1½ miles southwest of Cross Anchor, Spartanburg County, S.C. Shows prismatic crystals of sillimanite (s), biotite (b), quartz (q), and a little muscovite (m). Some sillimanite crystals are cut nearly normal to the *c* axis (showing rectangular cross sections with diagonal cleavage), and other crystals are cut nearly parallel to the *c* axis. Plane-polarized light.

limanite aggregates commonly occur as small platy lenses less than an inch in diameter; masses several feet across, consisting of nearly pure sillimanite, are found at several places. Small pegmatite lenses and quartz veins are commonly abundant in the rock. Large granite bodies occur in most areas of sillimanite schist.

Numerous samples of sillimanite schist, taken from road cuts, trenches, and drill holes, have shown that the average sillimanite content across widths of 50 feet or so is less than 10 percent in many places, though samples from some localities have shown a content of 15 to 20 percent. Low-grade schist or granite has been found by drilling at shallow depths below some surface exposures of high-grade rock.

DEPOSITS IN QUARTZ VEINS AND PEGMATITES

Large bladed crystals of light-gray to blue kyanite are common in quartz veins and in pegmatite in areas of kyanite schist and gneiss, especially in the Blue Ridge. Many of these deposits have attractive showings of large kyanite crystals, and prospecting and small-scale mining have been attempted in such deposits in North Carolina and Georgia; the operations, however, have not been profitable because of the small size and irregularity of the deposits.

RESIDUAL DEPOSITS AND PLACERS

Kyanite, sillimanite, and other insoluble minerals have accumulated in the residual soils overlying rocks containing these minerals as the result of the deep weathering and rock decay that have affected the Southeastern region. In some localities these insoluble minerals are more abundant in the soil than in the parent country rock. This is particularly true in some areas of sillimanite schist where abundent distinctive float of rock fragments or of sillimanite nodules or crystals has become concentrated in the soil and has been spread laterally from the point of origin. Under these circumstances, the float mantle may give the impression that the underlying body of sillimanite schist is larger and contains more sillimanite than it actually does. Abundant accumulations of large kyanite crystals are found in the soil overlying parts of the kyanite schist belt of Habersham and Rabun Counties, Ga. No information is available on the occurrence of andalusite in the residual soils of the pyrophyllite deposits that carry andalusite.

The Al_2SiO_5 minerals become concentrated in stream alluvium along with the other heavy minerals. Placer deposits containing abundant large subrounded kyanite crystals (fig. 23) have been mined in some streams that drain the kyanite schist belt of Habersham and Rabun Counties, Ga.; kyanite also occurs in terrace gravels which are 30 feet or more above present stream levels, and which are the remnants of ancient stream deposits.

Kyanite and sillimanite are among the heavy minerals in the Southeastern beach sands. Along the Atlantic coast between Charleston, S.C., and Miami, Fla., Martens (1935) found that the content of sillimanite and kyanite ranged from 3 to 13 percent of the total heavy-mineral content, and that sillimanite was several times more abundant than kyanite. However, in three samples of beach sand from the gulf coast of northwestern Florida, kyanite was far more abundant than sillimanite. Miller (1945) found the same situation in his study of the Florida beach sands: kyanite made up 30 to 45 percent of the heavy minerals in the Pensacola Bay area but only about 3 percent of the heavy minerals along the east coast of Florida. In the sands of Trail Ridge and other areas in central Florida, kyanite and sillimanite occur in about the same proportions as in the Atlantic beach sands. These inland sands usually contain only a few percent of heavy minerals, of which kyanite and sillimanite together make up from 5 to 15 percent of the total heavy minerals (Spencer, 1948; Thoenen and Warne, 1949). At the Trail Ridge titanium mine of the E. I. du Pont de Nemours & Co. near Starke, wet spiral concentrate contains 80 percent heavy min-

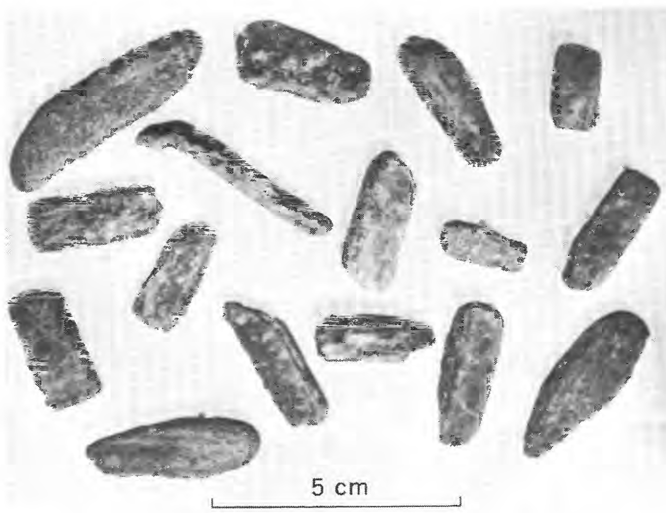


FIGURE 23.—Waterworn kyanite crystals from A. P. Green placer deposit on Raper Creek, about half a mile above junction with Soque River, Habersham County, Ga.

erals, which occur in the following proportions (Eng. Mining Jour., 1952):

	Percent
Titanium minerals	45
Staurolite	20
Zircon	15
Tourmaline	5
Sillimanite	5
Kyanite	4
Miscellaneous	6

The titanium minerals, staurolite, and zircon are separated as commercial products, but kyanite and sillimanite have not been recovered. Recent experimental work by the Bureau of Mines (Browning and others, 1956) on the zircon mill tailings from Trail Ridge and on similar material from the plant of the Titanium Alloys Manufacturing Co. at Jacksonville has yielded concentrates containing up to about 96 percent combined kyanite and sillimanite and a little corundum and zircon.

ORIGIN

GENERAL CONSIDERATIONS

The problems of origin of the Al_2SiO_5 minerals involve the conditions of temperature and pressure which prevailed during metamorphism and the chemical processes which brought about the present chemical composition of the rock. These physical conditions and chemical processes are only poorly understood. Why one of the Al_2SiO_5 minerals is found instead of another in certain rocks, or why two of them, or all three, occur together in some rocks, is in many cases not clear. The present state of knowledge about the conditions of formation of these minerals is briefly reviewed below.

Turning first to the experimental work on the synthesis of the Al_2SiO_5 minerals, we find that much remains to be learned about the temperature and pressure conditions and the fields of stability of these minerals. In early attempts at their synthesis (Vernadsky, 1890; Shepherd and others, 1909), a phase was formed that was first thought to be sillimanite because of its optical properties and slender prismatic crystal form. The same compound was found in porcelain; it was also formed by heating kyanite, andalusite, topaz, and dumortierite to high temperatures (Vernadsky, 1890). However, Bowen and Greig (1924) subsequently demonstrated that this so-called sillimanite has the chemical composition, $3\ Al_2O_3 \cdot 2\ SiO_2$; it was given the name "mullite" because of its occurrence on the Island of Mull in vitrified inclusions of aluminous sedimentary rocks in sills of mafic rock (Bowen and others, 1924). Navais and Davey (1925) showed that mullite and sillimanite could be distinguished by means of their X-ray diffraction patterns.

Experimental studies in recent years by several groups of workers have provided a limited amount of information about the phase equilibrium relations of the Al_2SiO_5 minerals. Roy and Osborn (1951, 1954) were unable to synthesize any of the Al_2SiO_5 minerals in their investigation of the system Al_2O_3–SiO_2–H_2O. They found that mullite seemed to be the only stable alumina-silica compound at temperatures above 575°C; pyrophyllite seemed to crystallize between 420° and 575°C; and various clay minerals crystallized in different temperature ranges below 420°C. Their colleague, Della Roy (1954) describes the formation of tiny crystals of andalusite in a study of the system MgO–Al_2O_3–SiO_2–H_2O (see also Roy and Roy, 1955). The data suggest that andalusite is a stable phase between 450° and 650°C at water pressures between 10,000 and 30,000 psi; the cations Mg^{++} and Ca^{++} may aid in the formation of andalusite.

Fyfe, Turner, and Verhoogen (1958, p. 165), state that Coes informed them in 1954 that he had synthesized all 3 Al_2SiO_5 polymorphs at 600° to 900°C above 20,000 atmospheres; in some runs all 3 polymorphs were formed together. Kennedy (1955) reports that sillimanite, kyanite, and pyrophyllite are in equilibrium at 700°C and 14,000 bars; he found that pyrophyllite breaks down to form a solid solution series between sillimanite and mullite at 550° to 600°C and 400 to 3,000 bars. Clark, Robertson, and Birch (1957) succeeded in establishing the equilibrium curve between kyanite and sillimanite from temperature of 1,000°C and pressure of 18,200 bars to 1,300° C and 21,000 bars; the kyanite field is on the high pressure side of the equilibrium curve. They found that quartz and corundum were generally formed below 1,000°C instead of kyanite or sillimanite.

The geologic characteristics of kyanite, sillimanite, and andalusite deposits give some general information about the conditions of formation of these minerals. Kyanite and sillimanite commonly occur in well-foliated schists and gneisses—rocks that have been regionally metamorphosed under the influence of heat and strong deformation. Andalusite is more abundant in less highly deformed rocks where recrystallization has taken place at high temperatures.

In some areas of argillaceous rocks that have undergone regional metamorphism, sillimanite occurs in zones nearest igneous intrusions and kyanite occurs farther away. Here, sillimanite was evidently formed at higher temperatures than kyanite. The classic example of zoning of this nature is in the southeast Highlands of Scotland where zones containing the following index minerals (arranged in the order of increasing temperature of formation) are found: Chlorite, biotite, almandine garnet, kyanite, and sillimanite. The work of Barrow, Tilley, and others in this region is summarized by Harker (1939) and Turner (1948). In Dutchess County, N.Y., kyanite, biotite, garnet, and staurolite occur in schists adjacent to a zone of higher grade sillimanite schists (Barth, 1936). In the Kings Mountain district, North Carolina–South Carolina, sillimanite occurs in quartzite and schist within, and adjacent to, a large body of quartz monzonite; kyanite is found at greater distances from the igneous mass.

Although sillimanite is generally regarded as a high-temperature mineral, Turner and Verhoogen (1951) have suggested that it is the stable form of Al_2SiO_5 over a very wide temperature range—

> from normal surface temperatures almost to the melting point at atmospheric pressure (p. 412) * * * there is reason to believe that andalusite (metastable) normally appears instead of sillimanite (stable) during contact metamorphism, merely because the velocity of reactions leading to sillimanite is almost infinitely slow (p. 386).

Heinrich (1952) has reported that in some quartz veins sillimanite appears to have formed later than kyanite or andalusite, "presumably at lower temperatures."

Kyanite seems to be stable over a very wide range of conditions of temperature and pressure. Turner (1948) cities examples of the occurrence of kyanite in the low-temperature greenschist facies, the moderate temperature albite-epidote amphibolite facies, the high-temperature amphibolite facies, and the very high temperature granulite and eclogite facies. Likewise, in the Kings Mountain district, North Carolina–South Carolina, kyanite occurs in rocks ranging from the greenschist facies to the amphibolite facies.

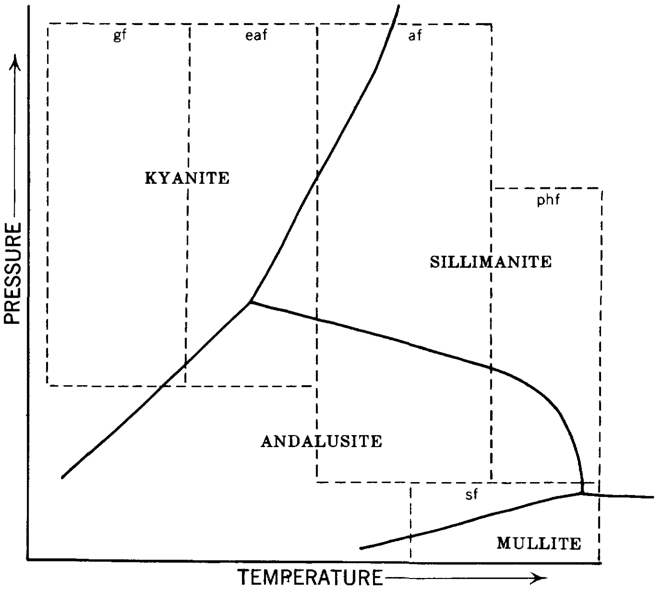
Because of the common occurrence of kyanite in regionally metamorphosed rocks and andalusite in thermally metamorphosed rocks, some investigators have concluded that kyanite forms most readily in the presence of shearing stress, and andalusite in its absence. Thus, Harker (1939) has called kyanite a "stress" mineral and andalusite an "antistress" mineral. However, numerous instances are now known where kyanite has evidently formed without the aid of shearing stresses. One of the most striking examples is its occurrence in druses in kyanite-quartz veins in Korea (Miyashiro, 1951); it seems to have been formed there from circulating solutions under hydrostatic pressure. In the deposits of the Southeastern States the many occurrences of kyanite in unfoliated pegmatites and quartz veins and of randomly oriented kyanite as aggregates and irregular veins in kyanite-quartz rock probably were formed under conditions of minimum shearing stress. Field evidence indicates that the concept of kyanite as a "stress" mineral is rather dubious.

Thompson (1955, p. 76–77) reaches this same conclusion from thermodynamic considerations. He also points out that extreme deformation may be evidence of extreme plasticity, and that very plastic materials cannot support strong shearing stresses. In other words, highly deformed foliated rocks could have recrystallized under conditions of low-shearing stress, rather than high-shearing stress as generally assumed.

Two of the Al_2SiO_5 minerals occur together very commonly, and all three of them are found together in a few localities. In the Southeast, andalusite and kyanite are closely associated in quartzose rock at the Brewer deposit and at Boles Mountain, S.C.; sillimanite and kyanite occur together in micaceous schist in the Warne–Sylva belt, North Carolina, and all three are found together in sillimanite-bearing quartzites in the Kings Mountain district, North Carolina–South Carolina. The association of the Al_2SiO_5 polymorphs together in quartzite of the Kings Mountain district is thought (p. 84) to record steps in polymorphic transformations during 1 or, perhaps, 2 periods of metamorphism.

These occurrences together of 2, or all 3, of the Al_2SiO_5 minerals have generally been regarded as caused by changing physical conditions during metamorphism; thermal metamorphism may have been followed by regional metamorphism, or vice versa (Harker, 1939, p. 323–343). Kyanite formed from chiastolite (andalusite) by regional metamorphism following thermal metamorphism has been studied in the Carn Chuinneag area of Scotland by Tilley (1935). The reverse relation, kyanite altered to andalusite, in the thermal aureole of a granite body in Scotland has been described by MacKenzie (1949), who also discusses occurrences of two of the Al_2SiO_5 minerals together at several localities in Europe that have been described by other authors. Kyanite, sillimanite, and andalusite have been found together in cordierite-bearing schist of the Belt series, central Idaho by Heitanen (1956); she attributes these associations to fluctuating conditions of temperature and pressure during complex thermal metamorphism superimposed on a regional metamorphism.

Using the general geologic relationships of deposits of the Al_2SiO_5 minerals as a guide, Miyashiro (1949) has attempted to express the physical conditions of formation of these minerals by means of a pressure-temperature diagram (fig. 24) that



EXPLANATION

gf
Green schist facies

eaf
Epidote amphibolite facies

af
Amphibolite facies

phf
Pyroxene hornfels facies

sf
Sanidinite facies

FIGURE 24.—Diagram showing Miyashiro's concept of the stability fields of kyanite, sillimanite, andalusite, and mullite. After Miyashiro (1949).

shows the stability fields of each of the minerals. If his diagram approximates the actual state of conditions, then the association of 2, or all 3, of the minerals together need not necessarily be the result of fluctuating conditions of temperature and pressure during metamorphism. It could be the result of changes in only one factor, such as a change in temperature under nearly constant pressure or a change in pressure with little change in temperature. Miyashiro evidently regards pressure as being very important in the formation of these minerals, because he suggests that "these minerals are useful as indicators of pressures of their formation." The opposite view of the importance of pressure in metamorphic reactions has been expressed by Yoder (1952, p. 617–618) in his discussion of studies in the $MgO–Al_2O_3–SiO_2–H_2O$ system. He believes that temperature and composition are the important variables, and that pressure is of minor significance.

Thompson (1955, p. 97) modifies Miyashiro's concept of the stability relationships of the Al_2SiO_5 minerals by adding fields for hydrous aluminum silicates; he believes that water may remain in the system to higher temperatures in thermal metamorphism than in regional metamorphism, which may delay or prevent the formation of kyanite from the hydrous aluminum silicates in thermal metamorphism (see next paragraph). Schuiling (1957, 1958) also proposes a phase diagram that is very similar to those of Miyashiro and Thompson but goes a step farther by inferring values for temperature and pressure. Clark, Robertson, and Birch (1957, 1958) suggest a phase diagram in which the triple point of the Al_2SiO_5 polymorphs lies at a higher pressure and lower temperature than in Schuiling's diagram. The phase diagram of Miyashiro (fig. 24) and its several variations just discussed all envision sillimanite as the high-temperature polymorph. Fyfe and others (1958, p. 164–165) offer two other diagrams of the hypothetical relations of the Al_2SiO_5 minerals in which sillimanite is regarded as the low-temperature form in one diagram and as the intermediate-temperature form in the other; these proposed diagrams do not seem to be so well based on experimental data or field relations as Miyashiro's diagram.

Water is generally present in rocks that are undergoing metamorphism, and is essential in the metamorphic processes. Aqueous solutions or gases are diffused through the rocks, and provide a medium that facilitates mineral recrystallization in response to temperature changes. Yoder (1952, p. 614–617) shows that in the $MgO–Al_2O_3–SiO_2–H_2O$ system under closed conditions, changes of only a few percent in the water content may cause important changes in the mineralogy. The pressure of water (and also of CO_2) is probably a significant factor in metamorphism, along with load pressure and temperature, according to Fyfe and others (1958, p. 15–17). Thompson (1955, p. 96–101) points out that the chances for water to escape are better under conditions of regional metamorphism than of thermal metamorphism, because the stronger deformation that accompanies regional metamorphism should tend to keep channels open for movement of fluids. Therefore, "devolatilization" could take place at lower temperatures in regional metamorphism than in thermal metamorphism, and this early removal of water may permit the recrystallization of the hydrous aluminum silicates at relatively low temperatures within the kyanite field, resulting in the formation of kyanite. In contact metamorphism, however, water may remain in the system to higher temperatures, and the breakdown of the hydrous aluminum silicates may be retarded until temperatures are reached at which andalusite, sillimanite, or mullite is crystallized.

A fundamental problem in understanding the chemical processes that may have taken place during formation of the Al_2SiO_5 minerals is whether all the aluminum was an original constituent of the rock before metamorphism, or whether the relative content of aluminum increased by some means during metamorphism. If the aluminum content was increased during metamorphism, was it by introduction of aluminum, or were other constituents removed to leave the rock relatively enriched in aluminum? If aluminum was introduced by hydrothermal fluids, was the aluminum of magmatic origin or was it derived from aluminous country rock, perhaps at considerable distance from its present site?

The apparent paragenetic relations of the Al_2SiO_5 minerals may be very misleading at some places. The important chemical reactions involving aluminum may have taken place before metamorphism, and the records of these transformations then may have been completely destroyed during metamorphism. For example, a body of igneous rock may be leached of practically all its constituents except Al_2O_3 and SiO_2 by hydrothermal fluids associated with volcanism and may later be recrystallized to kyanite-quartz rock by regional metamorphism. If none of the original minerals or other primary features are preserved, the kyanite-quartz rock may appear to be a metamorphosed sediment. Or, very minor chemical changes (see section on origin of quartzose deposits, p. 25) could have occurred in the waning stages of metamorphism, such as solution of kyanite and its recrystallization in quartz veins or slight replacement of kyanite by clay minerals, that could be incorrectly interpreted as evidence of the major process of origin.

Some of the fundamental problems of metamorphism, such as metamorphic differentiation, diffusion, and metasomatism, are involved in the chemical processes that may operate in the formation of the Al_2SiO_5 minerals. A lengthy discussion of these mechanisms, about which there is still much speculation, is not practical here. These problems are well reviewed in such recent texts as Turner (1948), Turner and Verhoogen (1951), Ramberg (1952), Barth (1952), and Fyfe and others (1958). Some of the chemical problems of origin of the Southeastern kyanite, sillimanite, and andalusite deposits are discussed below.

ORIGIN OF SOUTHEASTERN DEPOSITS

Some deposits of the Al_2SiO_5 minerals in the Southeast appear to have been formed by the metamorphism of aluminous sedimentary rocks, accompanied by little chemical change during recrystallization. In other deposits, the formation of the Al_2SiO_5 minerals probably was the result of chemical changes of considerable magnitude.

KYANITE GROUP MINERALS IN MICACEOUS SCHISTS AND GNEISSES, QUARTZ VEINS, AND PEGMATITES

Considering first the kyanite-bearing schists and gneisses that are widespread in certain areas, particularly in the Blue Ridge, it seems to us that these rocks have been formed by the recrystallization of aluminous sedimentary rocks with a minimum change in bulk composition during metamorphism. However, we have little new evidence to offer on this matter, because we have studied kyanite schists in detail only in the Kings Mountain district, North Carolina–South Carolina, and Farmville district, Virginia, where they occur in only small quantity in association with kyanite quartzite. Our conclusions rest mainly upon the evaluation of information gathered by others in the large areas of kyanite-mica schists and gneisses. These areas have been mapped in detail only in Habersham and Rabun Counties, Ga. (fig. 56), and at the north end of the Burnsville-Swannanoa area, North Carolina (fig. 39). In the north Georgia area the pattern of distribution of kyanite in thin persistent zones of graphitic mica schist around the flanks of a large dome clearly indicates that these kyanite-bearing layers are metamorphosed aluminous sedimentary rocks. The evidence is not so striking in the North Carolina area, but the occurrence of kyanite gneiss within a definite zone, 6 to 8 miles wide and over 30 miles long, seems to indicate that these rocks, too, were originally aluminous sediments. In the Tate quadrangle, Pickens and Cherokee Counties, Ga., some of the schists contain much more alumina than the average shale, as shown by the analyses of two graphitic mica schists given by Bayley (1928, p. 65):

	Al_2O_3 (percent)
Hiwassee schist	29.90
Nantahala slate	41.18

The abundant alumina in these schists is probably of sedimentary origin. The Al_2O_3 content of the average shale is 15.4 percent, according to Clarke (1924, p. 34). Kyanite schists are also present in the region; their relations to the graphitic mica schists are not discussed by Bayley, but it seems probable that they were formed from aluminous sedimentary rocks.

Kyanite is common in quartz veins and pegmatites in some areas of kyanite schist and gneiss. For reasons advanced below, we conclude that kyanite in the quartz veins and pegmatites is later than kyanite in the schists and gneisses, and that the kyanite in the quartz veins and pegmatites was formed from Al_2O_3 derived from the country rock. However, other workers have proposed that hydrothermal fluids from pegmatites or quartz veins have had an important part in the formation of kyanite in the micaceous schists and gneisses. Stuckey (1932, 1935) has concluded that the kyanite in the North Carolina schists was formed by metasomatic replacement by hydrothermal solutions from the quartz veins, pegmatites, and their parent magmas after metamorphism of the host rock. Furcron (1950) also thought that hot solutions derived from quartz veins, pegmatites, and granitic bodies were instrumental in formation of kyanite, but that the alumina was derived from the aluminous country rock and not from an igneous source.

In the Burnsville-Swannanoa area, North Carolina, for example, it is most unlikely that alumina in the kyanite schists could have been derived from pegmatites and their parent magmas, because the belt, 30 miles long, of kyanite schists and gneisses does not coincide with the area of most abundant pegmatite deposits, the Spruce Pine pegmatite district, lying just east of the north end of this belt. In many occurrences the kyanite crystals in the country rock—schist, gneiss, or quartzose rock—are generally conformable to the foliation, whereas kyanite in the intruding quartz veins or pegmatites is generally not oriented parallel to the foliation (fig. 25). Thus, the kyanite in the quartz veins and the pegmatites seems younger than the kyanite in the host rock. The vein or pegmatite fluids may have been contaminated by Al_2O_3 from the country rock. Or possibly both the alumina and the silica in some kyanite-quartz veins have been derived from aluminous country rock by means of metamorphic differentiation, as was suggested by Read (1933) for the origin of some quartz-kyanite veins in kyanite schists in Unst, Shetland Islands.

The bulk of the evidence, therefore, seems to us to point to the aluminous country rock as the source of the alumina now in the kyanite in the schists and gneisses and also in the pegmatites and quartz veins. More detailed field, petrographic, and chemical studies are needed in the large areas of kyanite schist and gneiss in order to gather more evidence on the source of the alumina and its behavior during metamorphism.

The sillimanite schists of the Piedmont and Blue Ridge belts consist chiefly of sillimanite-quartz-biotite-muscovite schists that are commonly graphitic. They are intruded by granite bodies and innumerable pegmatites. The problem of the source of alumina in the sillimanite schists is the same as that for the kyanite schists and gneisses. In the Piedmont belt of North Carolina, Hunter and White (1946) have suggested that sillimanite was formed

FIGURE 25.—Quartz-kyanite vein in kyanite quartzite at north end of Clubb Mountain, Lincoln County, N.C. Vein occurs in northwesternmost lens shown on pl. 9. Note sharp contact at the top of the vein between vertically oriented kyanite prisms and kyanite quartzite. The vein is practically horizontal and the foliation in kyanite quartzite is parallel to the plane of the photograph. Scale, 1 foot. Photograph by W. C. Overstreet.

in shear zones in the schists by solutions derived from the pegmatites. They conclude that muscovite was first formed through replacement of quartz, feldspar, and other minerals by hydrothermal solutions, and that sillimanite was formed later by replacement of micas, quartz, and garnet. Apparently they believe that the alumina was introduced by hydrothermal solutions, but this fact is not clearly stated in their article. Other geologists (Smith, L. L., 1945; Furcron and Teague, 1945; Furcron, 1950; Hash and Van Horn, 1951) have concluded that the sillimanite schists were formed by metamorphism of aluminous sediments; this view seems most probable to us also. Smith found no evidence for introduction of new constituents. Except for Smith, all these workers thought that the pegmatites provided heat and solutions that caused recrystallization of the aluminous country rock and the formation of sillimanite; it seemed to Smith that sillimanite was formed before the introduction of the pegmatites.

Sillimanite is generally intergrown very intimately with biotite and muscovite (fig. 21). Overstreet and Griffitts (1955) and L. L. Smith (1945) conclude that sillimanite has been formed by the reaction between micas and quartz under conditions of very high grade regional metamorphism. This relation is common in other regions also, and the formation of sillimanite from muscovite has been explained (Harker, 1939, p. 55–58; Turner, 1948, p. 85) by the following reaction:

$$\underset{\text{Muscovite}}{KAl_3Si_3O_{10}(OH)_2} + \underset{\text{Quartz}}{SiO_2} \rightleftarrows \underset{\text{Orthoclase}}{KAlSi_3O_8} + \underset{\text{Sillimanite}}{Al_2SiO_5} + \underset{\text{Water}}{H_2O}$$

However, it seems from our own limited petrographic studies of the sillimanite schists and from the statements of others that potash feldspar is not very common in these schists; oglioclase is typical, according to Overstreet and Griffitts (1955). If sillimanite was formed by reaction between mica (muscovite or biotite) and quartz, possibly much of the potassium was removed from the country rock, or it may be present as potassium feldspar in the pegmatites; the latter view is favored by Overstreet and Griffitts. Another possibility is that sillimanite was formed directly from argillaceous material in alumina-rich sediments, and that the breakdown of mica was not an important source of alumina.

KYANITE GROUP MINERALS IN QUARTZOSE DEPOSITS

Our studies of the quartzose deposits of Al_2SiO_5 minerals in the Southeast have led to the conclusion that these deposits have been formed in two distinct ways (see below). Some quartzose deposits of kyanite and sillimanite resemble metamorphosed sedimentary rocks, but other deposits of kyanite-quartz rock have characteristics of hydrothermal replacement deposits (Espenshade and Potter, 1953). The andalusite-pyrophyllite-quartz deposits are also of replacement origin.

METAMORPHOSED HIGH-ALUMINA SEDIMENTARY ROCKS

The deposits of kyanite quartzite in the Farmville district, Virginia, and of kyanite quartzite and sillimanite quartzite in the Kings Mountain district, North Carolina–South Carolina, probably are metamorphosed sedimentary rocks. The principal feature in both districts pointing to this origin is the occurrence of the high-alumina quartzite in persistent layers that have the distribution patterns of stratigraphic units. These layers occur in rather restricted stratigraphic positions in sequences of metamorphosed sedimentary and volcanic rocks. Many layers extend for distances of more than 1 mile; the longest body in the Farmville district is about 5½ miles long, and in the Kings Mountain district about 3½ miles long. Two thin layers of kyanite quartzite are parallel to each other, 20 to 100 feet apart, for a distance of over 1 mile in the Kings Mountain district. In this area kyanite-bearing conglomerate, kyanite quartzite, and kyanite schist grade into one another along the strike, and kyanite quartzite is interlayered with kyanite-staurolite quartzite and with barren quartzite. In both districts the high-alumina quartzites are strongly folded concordantly with the other metamorphic rocks.

These features are all characteristic of metamorphosed sedimentary rocks. There seem to be but two possible modes of origin for the high-alumina quartzites in the Farmville and Kings Mountain districts. They have either been formed from sandy sediments containing clay or bauxite that have been folded and metamorphosed to their present state with little bulk change in chemical composition, or they have originated by very selective replacement of certain beds, probably mainly sandstone. The latter possibility is discussed below, and it is concluded that this process is improbable for the origin of the high-alumina quartzites in these two districts.

The introduction of aluminum exclusively into porous sandstone beds before or during metamorphism does not seem probable. Aluminum metasomatism in areas extending over tens of square miles could hardly have been so selective that deposition of aluminum was vertically restricted to sandstone beds, only a few feet thick in many places, and nowhere formed discordant replacement masses in sandstone or adjacent beds. In addition to the quartzose rocks, aluminous schists occur in the Kings Mountain district; the aluminous minerals are not distributed irregularly through these schists, but occur in layers that probably represent the original bedding. If the Al_2SiO_5 minerals in these two districts are the result of aluminum metasomatism, no evidence whatever remains of the means by which this pervasive replacement took place. In both districts, quartz veins and pegmatites are present, but the Al_2SiO_5 minerals are absent from the pegmatites and are present in the quartz veins only where these veins cut the high-alumina rocks. In the Kings Mountain district, quartz veins occur in most of the metamorphic rocks; a quartz-kyanite vein that cuts kyanite quartzite at Clubb Mountain is definitely later than the kyanite quartzite (fig. 25). Pegmatite bodies in the Kings Mountain district are restricted to the margin of the Yorkville quartz monzonite, and show no relation to the distribution of most of the beds of high-alumina quartzite. Pegmatites are more widely distributed in the Farmville district; however, they do not contain kyanite and they are not foliated, indicating that they are younger than the well-foliated kyanite (or sillimanite) quartzite.

Tourmaline is very common in many quartz veins in the Farmville district, and occurs sparingly in quartz veins in the Kings Mountain district. However, tourmaline is an extremely rare mineral in the quartzose high-alumina deposits in these districts, and kyanite was not found in any of these tourmaline-quartz veins. Evidently the tourmaline mineralization had nothing to do with the formation of kyanite in these two districts. This is in contrast to the Bhandara district, India, where tourmaline-quartz veins are associated with kyanite deposits; Chatterjee (1931) has suggested that borates or boric acid accompanying the tourmaline mineralization acted as mineralizers to mobilize aluminum from chlorite-muscovite schists.

Mobilization of aluminum by metamorphic differentiation or other means in the Farmville and Kings Mountain districts seems to have been restricted to the formation of lenticular aggregates of coarse unoriented kyanite in kyanite quartzite and minor amounts of kyanite in some quartz veins that cut kyanite quartzite.

The weight of the evidence seems to us to point to an origin of these high-alumina quartzites in both the Farmville and Kings Mountain districts by the recrystallization of clay-quartz sand sediments. In the Kings Mountain district, sillimanite was formed instead of kyanite in the highest temperature zones near the Yorkville quartz monzonite.

REPLACEMENT DEPOSITS

Quartzose deposits of Al_2SiO_5 minerals that seem to be of replacement origin are the deposits of kyanite-quartz rock at Hagers Mountain, N.C., the Corbett property, North Carolina, Little Mountain, S.C., and Graves Mountain, Ga.; the andalusite-pyrophyllite-quartz deposits of the North Carolina pyrophyllite belt; and the Brewer mine and Boles Mountain, S.C. These replacement deposits all occur in the belt of volcanic flows, tuffs, and slates in the eastern Piedmont.

These replacement deposits are each made up of many lenticular segments, which are generally conformable to the enclosing schists, but which are partly discordant at Graves Mountain, Ga., and at the Brewer deposit, South Carolina. This discordance is one evidence of replacement origin.

Relict minerals or structures of the original rock are strong evidence of replacement in some deposits. Large grains of blue quartz, some being well-formed bipyramidal crystals, are abundant in some of the kyanite-quartz rock at Graves Mountain (p. 98; fig. 1). They are most likely relict quartz phenocrysts in an igneous rock that has been almost completely replaced by silicon and aluminum. At the Brewer deposit, South Carolina, the original structures of breccia tuffs and of bedding or foliation are preserved in silicified rock (Pardee and Park, 1948). Similar features are found in some of the North Carolina pyrophyllite deposits (Stuckey, 1928); masses or lenses of unaltered or only partly altered country rock are also found in some of these pyrophyllite deposits.

The quartz that forms the matrix is extremely fine grained in all these deposits, similar to much quartz of replacement origin. Silicification was the first stage of mineralization; the aluminous minerals vein and replace quartz. Kyanite occurs in irregular bodies and crosscutting veins in kyanite-quartz rock. Topaz forms irregular masses and networks of veins in the Brewer deposit; it also occurs in the Bowlings Mountain deposit, North Carolina. Pyrophyllite is invariably the latest aluminous mineral; it replaces quartz, kyanite, andalusite, diaspore, and topaz (figs. 17, 18, 19).

These deposits are all similar in chemical composition; they are composed principally of alumina and silica, but they vary considerably in their mineral associations. Some deposits have but one high-alumina mineral (in addition to white mica); the deposits of kyanite-quartz rock are at one extreme, and deposits of pyrophyllite-quartz are at the other. Several high-alumina minerals occur together in a few deposits, such as topaz, kyanite, andalusite, and pyrophyllite in the Brewer deposit and andalusite, kyanite, corundum, and diaspore at Boles Mountain, S.C.

RELATION OF HIGH-ALUMINA QUARTZOSE DEPOSITS TO VOLCANISM

Deposits of Al_2SiO_5 minerals in quartzose rocks are also found in the Western United States and in many other regions of the world. (See p. 6.) One characteristic that nearly all these deposits have in common, whether they appear to be metamorphosed sedimentary rocks or to have been formed by replacement, is that they occur with, or in the vicinity of, volcanic rocks. We believe that this interesting relationship provides a key to their genesis.

The replacement deposits in the Southeast and elsewhere typically occur in silicic volcanic rocks. Hot springs and solfataras are generally active in areas of silicic volcanic flows and tuffs, and through their activity the volcanic rocks may be thoroughly altered to mixtures of fine-grained silica and clay minerals; native sulfur, pyrite, cinnabar, and alunite are also common minerals in these deposits. This process of alteration seems to take place by the leaching and removal of nearly all constituents except silica, alumina, and titania, and may be accompanied by the deposition of sulfur and sulfur-bearing minerals.

Burbank (1950) has described rock alteration of this type in a large extinct caldera in the Red Mountain district near Silverton, Colo. At shallow depths (less than a mile) the rock has been altered to a mixture of very fine grained quartz and clay minerals (dickite, kaolinite, halloysite, and montmorillonite), diaspore, alunite, zunyite (very similar to topaz in composition), pyrite, and rutile. Cavities and caves, some of which contain minable sulfide ore bodies, have also been formed by leaching. Sericitic alteration has taken place beneath, and to the sides of, the sites of argillic alteration. Burbank discusses the possible mechanisms and problems of argillic and sericitic alteration in this area and other mineralized districts. He concludes that the two types of alteration were about contemporaneous in the Red Mountain district, that solutions under pressure were the agents of the deeper sericitic alteration, and that the vapors which formed in the low-pressure environment near the surface were the agents of the silicification and argillic alteration.

Comparable acid alteration has taken place in hot-spring areas that are still active. In the thermal spring areas of Yellowstone National Park (Allen and Day, 1935), the volcanic country rock has been altered to a siliceous residue, which is accompanied by clay in places; sodium in feldspar and in volcanic glass has been replaced by potassium at depth. Rock alteration in the Wairakei district, New Zealand, has been described by Steiner (1953) in a study of the petrology of cores from a group of drill holes; most of the holes were more than 500 feet deep, and 1 was 1,500 feet deep. The following alteration zones were distinguished by Steiner:

Alteration zones	*Characteristic minerals*
Sulfuric-acid leaching (shallow)	Kaolinite, opal, alunite
Argillization	Montmorillonite clays, pyrite
Zeolitization	Ptilolite, analcite(?)
Feldspathization (deep)	Adularia

Steiner remarks that quartz phenocrysts are the only primary constituents to survive in the intensely altered zone of sulfuric-acid leaching. Relict quartz phenocrysts are present in the kyanite-quartz rock at Graves Mountain, Ga. (p. 98). They also occur in quartz-andalusite rock, formed by replacement of quartz porphyry, in the Boliden district, Sweden (Ödman, 1941).

Lovering (1950) discusses the geochemistry of argillic and similar types of rock alteration in the shallow hot-spring environment and in the deeper zones of vein deposition. He summarizes the experimental work of other investigators on the decomposition of silicate minerals by both acid and alkaline solutions and concludes that kaolinitic and sericitic hydrothermal alteration are caused by acidic solutions. Kaolin minerals, silica, and alunite are the products of rock alteration by acidic hot spring waters. Lovering cites analyses of waters from several hot-spring areas which show that silicon and aluminum are present in solution in both acidic and alkaline waters. He discusses the studies of rock alteration by Anderson at Bumpass Hell Hot Springs, Lassen Peak, Calif., and by Rittmann at Solfatara, Italy. At both areas, all constituents including silicon and aluminum have been partly leached in the zones of more intense alteration. Thus, rock alteration in different areas of hot springs and solfataras has resulted in end products that may consist of porous masses of silica, or silica, alumina, and titania. It must be realized that considerable amounts of silicon and aluminum may actually be removed in the leaching process; on the other hand, silicon and (or) aluminum may be deposited by the altering solutions under some circumstances.

This type of rock alteration may have been active in the formation of some of the Southeastern deposits of aluminous minerals in quartzose rocks. Similar deposits of pyrophyllite, alunite, and quartz in Mesozoic volcanic rocks at Kyuquot Sound, British Columbia, were thought by Clapp (1915) to have been formed by solfataric processes. Stuckey (1928) states that hydrothermal activity may have taken place at shallow depths in the Southeastern deposits; however, he favors the view that pyrophyllite was formed by hydrothermal solutions from granitic magmas at intermediate temperatures and pressures after metamorphism of the volcanic rocks. D. E. White (written communication, 1956) is doubtful that this type of alumina-silica deposit could be formed through surficial leaching by acid spring waters, with acid derived by oxidation of H_2S with atmospheric oxygen. He points out that deposits formed in this way are generally small, are restricted to, or near, the water table, have a different paragenesis (aluminous minerals formed before silica), and are not known to have undergone appreciable fluorine fixation. White considers that the deeper alumina-silica deposits of the type described by Burbank (which contains the fluorine-bearing aluminum silicate zunyite) and Lovering are formed by hypogene acid leaching that probably does not involve atmospheric oxygen; he agrees that it may be possible that the alumina-silica replacement deposits of the Southeast have formed by similar processes.

The environment of formation of these replacement deposits of quartz, pyrophyllite, kyanite, andalusite, and topaz in the Southeast remains a problem. Some kyanite-quartz deposits may be masses of volcanic rock that were first altered by solfataric activity and then metamorphosed to the present mineral assemblage. Other deposits, such as some andalusite-pyrophyllite-quartz deposits, for example, might represent the deeper zones of extensive solfataric centers. Possibly in some places the rock alteration was contamporaneous with mild metamorphism of the volcanic rocks.

Deposits of kyanite-quartz rock and sillimanite-quartz rock that seem to be metamorphosed sediments might have several possible relationships to a volcanic environment. These deposits probably were formed by the metamorphism of beds of sandy clay or clayey sand, which might have been formed in several ways. Some volcanic rocks are readily weathered to very clayey soils under certain conditions; some volcanic soils from Java, Sumatra, and Hawaii have been found to carry free alumina (Clarke, 1924, p. 502), and the ultimate product of thorough weathering can be clay or bauxite. This material then might be eroded and transported by streams to a site of deposition, such as a lake basin. The parent sediment of kyanite quartzite may have been a mixture of (a) quartz sand derived from siliceous residue of hydrothermal origin or from some quartz-bearing rock, and (b) transported clay that has been derived from weathered basalt (Farmville district) or from more silicic volcanic rocks (Kings Mountain district). High-alumina clays of probable sedimentary origin are associated with volcanic rocks at several places in the Pacific Coast States. Some geologists have regarded these clays as being of volcanic origin, but Allen (1946) has given evidence for the sedimentary origin of the following clay deposits: Ione clay, California; Cowlitz clay deposit, Washington; and the Hobart Butte and Molalla clay deposits in Oregon.

Sedimentary deposits of clay and quartz sand in a volcanic terrane might also be formed by the erosion of hydrothermal silica and clay from a solfataric center and deposition of the material in a restricted basin that was uncontaminated by other sediments. In this way, alumina-silica deposits of sedimentary origin might occur in the same region as alumina-silica deposits of hydrothermal origin.

The basic feature of both these processes—hydrothermal leaching and weathering—is the removal of practically all constituents except alumina and silica; a certain proportion of alumina and silica might be removed, too. Titania is also a final product of both processes, which doubtless explains the widespread occurrence of small amounts of rutile in the deposits of Al_2SiO_5 minerals in quartzose rocks.

ORIGIN OF HIGH-ALUMINA QUARTZOSE DEPOSITS IN OTHER REGIONS

Various modes of origin have been ascribed to quartzose deposits of high-alumina minerals in other parts of the world. In the Picuris Range, N. Mex. (Montgomery, 1953), beds of kyanite quartzite and sillimanite quartzite, ranging from a few feet to about 25 feet in thickness and extending for distances of 1 mile or more, occur in a series of barren quartzite beds that is over 2,500 feet thick. The beds of kyanite and sillimanite quartzites were evidently formed by regional metamorphism of clay-rich beds. Hydrothermal activity associated with later quartz veins caused reworking and some segregation of the high-alumina minerals along the quartz veins.

Kyanite quartzite deposits in Kenya (Temperley, 1953) seem to be metamorphosed sedimentary rocks very similar to those in the Farmville district, Virginia, and are likewise associated with biotite and hornblende gneisses. Temperley points out, however, that they could not have been pure clays because their molecular ratio of SiO_2 to Al_2O_3 is too high. He finds that loesses from different regions have molecular ratios of SiO_2 to Al_2O_3 corresponding to the ratio in the kyanite quartzites and suggests as a possible mode of origin that the rocks were originally loesses whose compositions were modified by metamorphic differentiation. The SiO_2–Al_2O_3 molecular ratio of some bentonites and river silts also fall in this range. Conversion of any of these materials into alumina-silica rock would require the removal of large amounts of sodium, potassium, calcium, magnesium, and iron during metamorphism. As an alternate form of origin, Temperley proposes that the original rock was sandstone, and that aluminum was introduced into the sandstone by migration from aluminous sedimentary rocks during metamorphism. He regards this mode of origin as more probable but admits that this theory is not altogether satisfactory.

Kyanite quartzite and kyanite-quartz schist deposits at Lapsa Buru, India (Dunn, 1929) are closely associated with hornblende schist, and Dunn has suggested that the kyanite rocks are metamorphosed clays that had been formed originally from the weathering of basalt. Dunn (1933) later suggested that aluminum may have been reworked or segregated from aluminous sedimentary rocks during metamorphism. He has modified this view further (1937), and now thinks that magmatic waters may have been active in segregating aluminum, or in removing other constituents to leave the rock enriched in aluminum.

At White Mountain in the northern Inyo Range, Calif. (Kerr, 1932; Lemmon[4]), lenticular bodies of high-alumina minerals occur in quartzite that is associated with metamorphosed volcanic rocks; these rocks are intruded by quartz monzonite. Andalusite is the most abundant aluminous mineral and is commonly accompanied by corundum, quartz, muscovite, pyrophyllite, diaspore, alunite, rutile, and lazulite; topaz, tourmaline, barite, and other minerals are also present in lesser amounts. The deposit was apparently formed in two stages: thermal metamorphism of aluminous sedimentary or volcanic rocks, followed by hydrothermal activity that caused formation of such minerals as pyrophyllite, muscovite, alunite, and lazulite.

A somewhat similar deposit occurs at Semis Bugu, Kazakstan, U.S.S.R. (Ozerov, 1933). Lenticular bodies of high-alumina rock occur in fracture zones in silicified volcanic flows and tuffs (called secondary quartzite by Ozerov) that are intruded by granite and granodiorite. The lenses have strong mineral zoning, andalusite being the principal mineral in the outer portions and corundum predominating in the center. Quartz, muscovite, hematite, and minor amounts of diaspore, pyrophyllite, alunite, rutile, pyrite, barite, and zircon are also present. Ozerov concludes that the deposit was formed by the action of magmatic fluids during stages of declining temperature and changing composition. The volcanic rocks were silicified at an early stage; decomposition of feldspar provided Al_2O_3 and SiO_2 for the formation of andalusite, which was later replaced by corundum.

The dumortierite-andalusite deposit at Oreana, Nev. (Kerr and Jenney, 1935), occurs in quartz-sericite schist (originally rhyolitic and trachytic tuffs) that is intruded by quartz monzonite and granite porphyry. Mineralization seems to have taken place in pneumatolytic and hydrothermal stages by the action of magmatic fluids on alumina-rich zones in the tuffs.

Bodies of quartz-sillimanite rock occur in kyanite schist and gneiss at Mount Crawford near Williamstown, South Australia (Alderman, 1942, 1950). Kyanite-bearing pegmatites and quartz veins are also present. The sillimanite is extensively altered to clay (mainly kaolinite and minor amounts of dickite), and kyanite is altered to damourite. Alderman concludes that sillimanite and kyanite were formed through metasomatism of schists by high-alumina fluids of magmatic origin at high temperatures. During the last phase of mineralization, lower temperature hydrothermal solutions altered sillimanite to clay and kyanite to mica.

[4] Lemmon, D. M., 1937, Geology of the andalusite deposit in the northern Inyo Range ,Calif.: Stanford University, Doctor of Philosophy dissertation.

ECONOMIC CONSIDERATIONS

USES OF KYANITE, SILLIMANITE, AND ANDALUSITE

Kyanite, sillimanite, and andalusite (each having the same chemical composition, Al_2SiO_5, and containing 63.2 percent Al_2O_3), as well as topaz and dumortierite (both similar to the Al_2SiO_5 minerals in chemical composition), are used, or can be used, in the manufacture of high-alumina refractories and ceramic articles. These minerals are sometimes called the "sillimanite group." Kyanite occurs more commonly in minable deposits than do the other minerals of the sillimanite group, and therefore it has been used to a greater extent in the manufacture of mullite materials.

When fired at high temperatures, the Al_2SiO_5 minerals are transformed to a mixture of mullite ($3Al_2O_3 \cdot 2SiO_2$) and silica glass. The temperatures of conversion are different for the 3 minerals: kyanite converts to a mixture of mullite and silica glass between 1,100° and 1,480°C, andalusite between 1,350° and 1,450° C, and sillimanite between 1,550° and 1,650°C (Riddle and Foster, 1959 p. 897). Pure mullite, which contains 71.8 percent Al_2O_3, is the only form of alumina and silica that is stable at high temperatures; it melts at about 1,810°C. Mullite is also a constituent of ceramic articles made from other minerals composed primarily of alumina and silica, such as pyrophyllite, kaolinite and similar clays, diaspore, and mixtures of bauxite and silica.

Refractories made from the sillimanite group of minerals have a higher content of mullite than firebricks made from ordinary clays, and therefore can stand more severe temperatures. These mullite refractories maintain their strength to high temperatures, they have low thermal expansion and can withstand the effects of rapid temperature changes, and they are resistant to the corrosive action of certain types of fluxes. About 50 percent of the mullite refractories consumed is used as refractory linings for metallurgical furnaces and about 40 percent as lining for glass furnaces; the remainder is used principally in manufacturing kiln furniture and heavy-duty porcelain ware.

Kyanite, with specific gravity ranging from 3.56 to 3.67, undergoes a large expansion in volume when converted to mullite, whose specific gravity is between 3.03 and 3.16. Sillimanite and andalusite have only slight volume changes during conversion to mullite. Kyanite produced in the United States is a fine-grained flotation concentrate that expands and disintegrates to finer mullite particles when calcined. The fine-grained domestic kyanite and mullite can be used satisfactorily in refractory cements, mortars, plastics, and ramming mixtures; but they are not suitable by themselves in making refractory bricks, because the fine-grained material does not bond very well. The massive lump kyanite imported from India and Kenya, however, converts to mullite without disintegration. This coarse-grained mullite bonds excellently in bricks and other shapes, and can be mixed with certain amounts of the fine-grained domestic kyanite to make high-quality refractory bricks. The lump kyanite imported from India and Kenya has been an essential material and has been known as strategic-grade kyanite because no sizable domestic deposits of kyanite of comparable quality are known.

In recent years processes have been developed for making synthetic mullite from domestic raw materials; the product is as good as mullite made from imported strategic-grade kyanite. Synthetic mullite may be made by sintering or fusing mixtures of aluminous and siliceous materials of appropriate composition. Much of the synthetic mullite is made from low-iron siliceous bauxite; some is made from mixtures of Bayer-process alumina and silica. It can also be made from domestic kyanite concentrates and high-alumina clays. According to Gunsallus (1955, p. 412),

> The development of synthetic mullite assures the United States of self-sufficiency in raw materials for mullite-refractories manufacture, and in 1954 kyanite was removed from the list of critical and strategic materials for stockpiling. The stockpile objective for kyanite was reached in 1952.

The properties, treatment, and uses of the sillimanite group minerals are discussed at greater length by Riddle and Foster (1949); brief descriptions of domestic and foreign deposits and a comprehensive bibliography are included in the article. Different aspects of the industry are covered in papers by Watkins and Wolff (1952) and Gunsallus (1955).

HISTORY OF MINING

Much of the kyanite produced in the United States has come from deposits in Virginia and South Carolina; it has also been produced in quantity from deposits in California, Georgia, and North Carolina. Most imports of kyanite have come from India, Kenya, and the Union of South Africa. Andalusite has been mined in California and Nevada; some andalusite has been imported from the Union of South Africa. Very little sillimanite has been produced in this country, but it has been mined in India and Australia. Dumortierite has been mined in Nevada and topaz in South Carolina. The productive deposits of kyanite, andalusite, dumortierite, and topaz in the United States and the periods of their activity are listed in figure 26.

Nearly all the kyanite produced in the Southeastern States has come from mines at Baker and Willis Mountains, Va., Celo Mountain, N.C., Henry Knob, S.C., and the Clarkesville district, Georgia. A little kyanite has been shipped from small mines in the Blue Ridge area of North Carolina and Georgia.

Kyanite was first produced in the Southeast at Baker Mountain, Va., by the McLanahan-Watkins Co. in the early 1920's. The kyanite was separated from kyanite quartzite by a grinding and tabling process that was one of the first attempts in this country to beneficiate kyanite-bearing rock. The mine seems to have been idle from 1926 until 1937, when it was acquired by the Phosphate Recovery Corp. which explored the deposit by diamond drilling and installed a flotation plant. Production was at the rate of about 35 tons of kyanite concentrates a day by 1940, when the operation was reorganized as the Kyanite Products Corp. The property was purchased early in 1945 by the Kyanite Mining Corp., and has been operated by that company continuously since then. Mining at the kyanite deposit of Willis Mountain, Va., was started in 1957 by the same company.

Kyanite production at Celo Mountain, near Burnsville, N.C., was begun by Celo Mines, Inc., about 1934. Kyanite, garnet, and roofing mica were recovered from kyanite schist by means of dry tables and electrostatic separators; a flotation plant was installed in 1939. Operations were suspended in 1941 and resumed later that year by Mas-Celo Mines, Inc. The mine closed again in June 1942, and was reorganized as the Yancey Cyanite Co. in 1943. Production began again in February 1943 on a schedule of 12 tons of kyanite concentrates daily, but operations ceased in January 1944; the mine has been closed since that date. Gradually declining grade of the mill feed caused difficulties during the last few years of operation.

Kyanite mining was started in the Clarkesville district, Habersham County, Ga., about 1932 by the Georgia-Carolina Minerals Corp. This company, and successor companies, under the supervision of Philip S. Hoyt, worked a few weathered schist deposits, residual soil deposits, and placer deposits until about 1940. Kyanite, quartz sand, roofing mica, and flake graphite were recovered from the weathered schist. In 1938, E. C. Noble built a mill to recover kyanite and vermiculite from schist. The A. P. Green Fire Brick Co. of Mexico, Mo., took over this operation

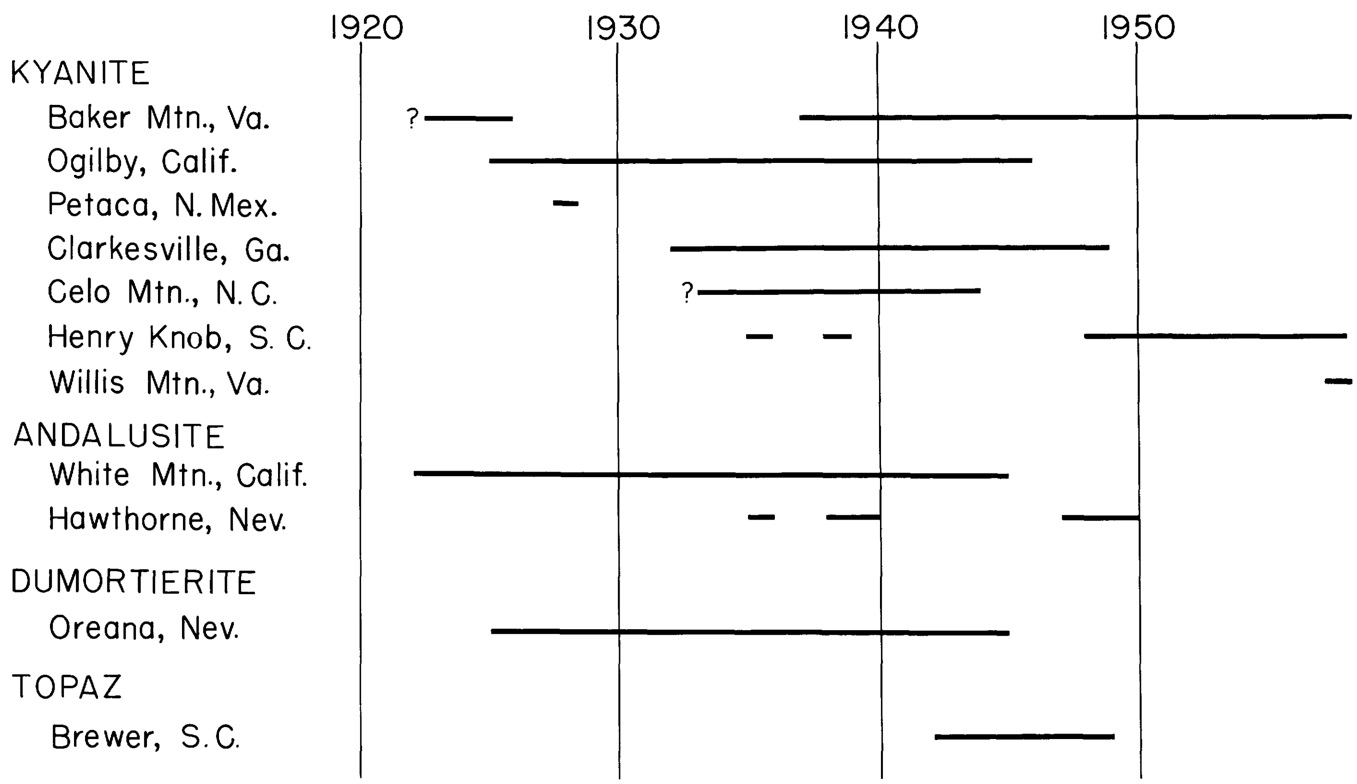


FIGURE 26.—Periods of production at major domestic deposits of kyanite, andalusite, dumortierite, and topaz.

in 1939, and later worked a placer deposit on Raper Creek. Mining ceased in the district in 1949.

Lump kyanite ore was shipped from Henry Knob, York County, S.C., in 1935 and 1938 by B. J. Lachmond (or Lockmund). In 1948, Commercialores, Inc., began opencut mining at Henry Knob, producing kyanite concentrates by flotation; production has been continuous since then.

In the 1920's and early 1930's small shipments of lump kyanite gathered from pegmatites and quartz veins in the Blue Ridge area of North Carolina and Georgia were made by Philip S. Hoyt, and perhaps others.

Complete production records for the kyanite mines in the Southeast are not available. Since 1950, all the production in the United States has come from Baker and Willis Mountains, Va., and Henry Knob, S.C.; in 1950 and 1951 it was estimated to range between 16,000 and 20,000 tons of kyanite concentrates annually (Watkins and Wolff, 1952, p. 10). Production of crude kyanite increased annually from 1952 through 1955, according to the Minerals Yearbook (U.S. Bur. Mines, 1952–1955). In 1954, kyanite concentrates from the Baker Mountain mine amounted to 15,608 tons (Corriveau, 1955, p. 4). Kyanite is recovered from kyanite quartzite by floation processes at those 3 mines. The concentrates are sold as kyanite or mullite (calcined kyanite) in various grain sizes: 35–, 48–, 100–, and 200–mesh.

The amount of sillimanite produced in the region has been negligible. Stuckey (1937, p. 75) states that in 1932 and 1933, Philip S. Hoyt shipped several carloads of sillimanite from Clay County, N.C. During the exploration of the Piedmont sillimanite schist belt in Georgia, South Carolina, and North Carolina in 1945 and subsequent years, large samples of sillimanite schist were taken from different localities for beneficiation and ceramic testing, but no commercial shipments have been made. High-quality refractory bricks were made from sillimanite concentrates at the Bureau of Mines Electrotechnical Laboratory, Norris, Tenn.

Andalusite has been produced only as a minor constituent, not recognized until recently, in pyrophyllite ores at several deposits in North Carolina; it has not been separated from pyrophyllite by milling processes. Massive topaz was produced from the Brewer mine, Chesterfield County, S.C., from 1941 to 1948. The recorded production for 3 years of this period amounts to 3,577 tons; the unrecorded production was probably several thousand tons.

ECONOMIC GEOLOGY

KYANITE DEPOSITS

Grade.—Nearly all the kyanite produced in the Southeastern States has come from deposits of kyanite-quartz rock and kyanite schist or gneiss. The kyanite content varies considerably from deposit to deposit, but generally it is highest in kyanite-quartz rock, commonly ranging between 20 and 30 percent compared with a range of 5 to 15 percent in the better deposits of kyanite schist or gneiss. The higher grade of the quartzose deposits is doubtless one of the reasons why mining has been continued at the quartzose deposits of Henry Knob, S.C., and Baker and Willis Mountains, Va., whereas mining of the deposits of kyanite schist and gneiss of the Clarkesville district, Georgia, and Celo Mountain, N.C., has ceased. The kyanite schist in the Clarkesville district was thought by R. W. Smith (1936) to have an average of 6 to 8 percent kyanite in places favorable for mining. Chute (1944,) states that the ore at Celo Mountain was reported to carry between 10 and 11 percent kyanite at the beginning of operations, but that in the latter half of 1943 the grade had declined to between 7.0 and 7.5 percent. Kyanite content of channel samples taken at Celo Mountain is as much as 18 percent; about 55 percent of the samples contained less than 10 percent kyanite (table 9). Kyanite in the ore mined at the quartzose deposits of Baker Mountain and Henry Knob is somewhat variable; the average grade of Baker Mountain ore mined during the month of October 1954 was 15 percent kyanite, according to Corriveau (1955, p. 2). Recent prospecting of the quartzose deposit at Willis Mountain (22 miles northeast of Baker Mountain) has shown that much of that rock contains between 25 and 35 percent kyanite (Jones and Eilertsen, 1954, p. 18–37).

The large kyanite crystals that are so common in some quartz veins and pegmatites in areas of kyanite schist in Georgia and western North Carolina were encouraging to the prospecting of these deposits at an early date; later it became evident that such deposits were too small to be profitably mined for kyanite. No reliable information is available on their kyanite content; but it probably seldom exceeds 20 percent, and it may approximate the average kyanite content of the country rock. Information on the grade of kyanite in residual soil and placer deposits is likewise very meager. Because of its resistance to weathering, kyanite may accumulate in considerable amounts in residual soils of kyanite schist areas; locally, it may become concentrated in more abundance in the soil than in the bedrock, thus giving a misleading impression of the kyanite grade of the bedrock. Concentrations of kyanite in both residual soils and stream sediments have been mined in the Clarkesville district, Georgia. The occurrence of kyanite in beach sands is discussed on pages 18–19.

Structure.—We believe that kyanite schist and gneiss and many deposits of kyanite-quartz rock were originally aluminous sedimentary rocks that were later highly deformed and strongly metamorphosed. The present structure of these deposits thus depends partly upon the original thickness and extent of the aluminous beds and partly upon whatever modifications have since occurred by folding, faulting, or by redistribution of alumnia during metamorphism.

Deposits of kyanite-quartz rock in the Kings Mountain district, North Carolina-South Carolina., and Farmville district, Virginia, which are considered as having been formed by the metamorphism of beds of clay and quartz sand, range from small lenses 100 feet or so long and a few feet thick to layers that extend for several miles and are as much as 200 or 300 feet thick. These metamorphosed beds have been deformed by both major and minor folds, and generally dip at steep angles conformable with the foliation. Extensive deposits, such as those at Willis Mountain and Woods Mountain, Va. (pl. 2), and Crowders Mountain and The Pinnacle, N.C. (pl. 7), occur in large complex folds; bedding appears to have been greatly thickened in the crests and troughs of folds. In the deposits of Willis Mountain and Woods Mountain, plunges of both major and minor fold axes seem to be consistent and are paralleled by the plunges of other linear structures; these features, observable at the surface, therefore give an indication of the underground trend of the deposit. On the contrary, plunges of minor fold axes at Crowders Mountain and The Pinnacle are very erratic, and their relation to the underground structure is not well understood. The lenticular bodies of kyanite-quartz rock at Henry Knob (pl. 10) appear to be the segments of strongly folded and sheared beds of kyanite quartzite that were originally continuous; the individual lenses are nearly vertical, and probably plunge steeply to the southwest parallel to the plunge of lineation. Kyanite quartzite at Baker Mountain, Va., is in a gently dipping layer that is deformed on a small scale by irregular minor folds and probably also by shears. In prospecting and mining of these deposits, careful attention should be given to the detailed distribution and structure of the kyanite-quartz bodies in order to gain a better understanding of their structure; this knowledge may make it possible to avoid low-grade or barren areas in mining.

The kyanite mica schist and gneiss deposits of the Burnsville-Swannanoa district, North Carolina, Clarkesville district, Georgia, and probably also in other areas that are less well known, occur in zones or belts that extend for many miles (figs. 39, 56). Within these zones, layers of kyanite schist, which are as much as 50 feet or more thick, alternate with layers of rock that are poor in, or barren of, kyanite; these layers were evidently alternating beds of clay-rich and clay-poor sediments originally and were later deformed by large folds with many minor folds. Small-scale shearing and faulting are present at the Celo Mountain deposit, North Carolina, and probably also at other places. The structure of the kyanite-rich layers in these deposits has not been studied in detail; it is probably largely dependent upon folding and faulting.

The kyanite-quartz deposits that seem to be of replacement origin (such as Graves Mountain, Ga., and Hagers Mountain and the Corbett deposit, North Carolina) are made up of irregular lenticular bodies that generally occur in elongated zones. The underground structure of these deposits is not known because none of them has been explored. The shapes and distribution of the kyanite-quartz bodies underground may be found to be very irregular or conformable to some pattern, such as a joint system. Prospecting or mining in these deposits should be guided by geologic study.

SILLIMANITE DEPOSITS

Grade.—Sillimanite content is also generally higher in the quartzose deposits than it is in sillimanite schist or gneiss. The only sillimanite-quartz deposits in the Southeast are in the Kings Mountain district; they contain 30 percent or more sillimanite in places. In contrast, the better grade sillimanite schist seeems to have an average sillimanite content of about 10 percent; richer layers may carry 15 or 20 percent. Teague (1950, p. 787) states that chip samples of sillimanite schist from Hart County, Ga., showed that 1 zone contained about 12 percent sillimanite across a width of 109 feet, and another zone averaged 10 percent across 85 feet.

In the quartzose deposits of the Kings Mountain district, sillimanite occurs both as coarse prismatic crystals and as small fibrous crystals thoroughly intermixed with abundant quartz; andalusite is present locally. Benefication tests by the U.S. Bureau of Mines (table 11) indicate that the coarse sillimanite crystals are easily separable, but that very fine grinding would be necessary to liberate the fine fibrous sillimanite from quartz. This difficulty is a handicap to the potential economic value of the sillimanite quartzite deposits.

Sillimanite in micaceous schist or gneiss is commonly finely fibrous and intergrown with fine white mica; in some places it also occurs as coarse crystals or in small nodular aggregates of fibrous crystals. Beneficiation tests have shown that a good sillimanite concentrate can be made of the coarser sillimanite in some deposits; however, this concentrate may have a high iron-oxide content and acid leaching may be necessary to remove the iron (Hudson, 1946; Teague, 1950). It is often difficult to make a satisfactory sillimanite concentrate from rock containing sillimanite that is intimately intergrown with white mica (Hudson, 1946; Hash and Van Horn, 1951). To separate the sillimanite from the mica, very fine grinding may be necessary; in some concentrates, the percentage recovery of sillimanite may be very low. Careful beneficiation tests would be essential in the evaluation of a sillimanite deposit.

Structure.—The sillimanite quartzite deposits of the Kings Mountain district seem to be metamorphosed sedimentary rocks that have undergone a higher degree of metamorphism than the nearby deposits of kyanite quartzite. The sillimanite quartzite bodies range from lenses a few hundred feet in length to layers several thousand feet in length; their thickness is generally less than 10 feet, but reaches 50 feet in places. Parts of some lenses are practically barren of sillimanite. The longer deposits have curved trends due to folding and some of the shorter lenticular bodies are in curved zones (pl. 7); the lenses are probably the remnants of a once-continuous bed or beds that have become separated by close folding and shearing.

Sillimanite schist and gneiss also seem to be metamorphosed aluminous sedimentary rocks. Alternating layers of sillimanite-rich schist and sillimanite-poor schist occur in extensive linear zones or large irregular areas. The nature of distribution of sillimanite schist has been demonstrated very well in the Shelby quadrangle, North Carolina. (Yates, Overstreet, and Griffitts, written communication, 1954), where it forms large curved zones, as much as several miles wide, that are associated with biotite schist. These curved bodies of sillimanite schist are evidently highly folded and perhaps also faulted. Probably similar complex structures exist in the sillimanite schist of other areas. Some sillimanite schist layers and zones in the Warne-Sylva belt of western North Carolina extend for miles with little deviation in strike (Hash and Van Horn, 1951). Sill-like bodies of granitic rock cut both sillimanite and biotite schists in the Shelby quadrangle. Pegmatite and granite are widespread in other areas of sillimanite schist. In some places where float of sillimanite schist is abundant on the surface, trenching or drilling has shown that granite or schist that is lean or barren in sillimanite occurs at depth. The sillimanite schist fragments have evidently accumulated as float on the surface because of high resistance to weathering. The absence of sillimanite schist beneath such areas may be the result of lateral movement of sillimanite float in the soil, or it may be due to complex structural conditions.

ANDALUSITE DEPOSITS

In the Southeast, andalusite occurs as a minor constituent of schist and quartz veins in some areas, it is present in some sillimanite quartzite in the Kings Mountain district (where it is locally more abundant than the sillimanite), and it is rather common in some pyrophyllite-bearing quartzose deposits of replacement origin. This last type of deposit seems to be the most promising as a potential source of andalusite. Other high-alumina minerals—corundum, diaspore, topaz, kyanite, and pyrophyllite—commonly accompany andalusite in these quartzose replacement deposits. Information on the content of high-alumina minerals in these deposits is available only for the Brewer deposit, South Carolina. Drill-hole samples taken there by the Bureau of Mines show that 70 out of 231 core sections contain over 15 percent combined topaz, andalusite, and kyanite (Peyton and Lynch, 1953, p. 7). Because of the similar physical properties of most of the high-alumina minerals, it may prove difficult to separate andalusite from some of the other high-alumina minerals by ore-dressing methods. However, separation of andalusite would probably not be necessary because the minerals are similar in chemical composition. Some andalusite-pyrophyllite-quartz deposits are lenticular or roughly circular in surface outline, having diameters of several hundred feet. No information is available on their structure, but it seems probable that they are pipelike bodies that may have considerable vertical extent. Other deposits are a thousand feet or more long; they may be tabular veinlike bodies.

ORE RESERVES

KYANITE

Kyanite-quartz rock of the type being mined at Baker and Willis Mountains, Va., and Henry Knob, S.C., forms very large reserves of material that contains between 10 and 30 percent kyanite. The average grade of this type of ore is not known, but the kyanite in several of the larger deposits exceeds 20 percent. Reserves of kyanite-quartz rock are as follows:

Measured and indicated reserves of kyanite-quartz rock containing 10 to 30 percent kyanite

[This consists of ore minable by opencut methods to depths that range from 50 to 200 feet]

	Tons (millions)
Farmville district, Virginia (includes Willis Mountain and neighboring deposits, Woods Mountain, and Baker Mountain)	50
Kings Mountain district, North Carolina–South Carolina (includes Crowders Mountain, The Pinnacle, Shelton property, Henry Knob, and Clubb Mountain)	40
Other districts	10
Total	100

Inferred reserves of kyanite-quartz rock containing 10 to 30 percent kyanite

[This consists of the depth extensions of known deposits, and would be minable by underground methods]

All districts	more than 50

The tonnage of kyanite-bearing gneiss and schist is much larger than the tonnage of kyanite-quartz rock, but the kyanite gneiss and schist are appreciably lower in grade. Brobst (written communication, 1953) estimates that to a depth of 50 feet there are about 300 million tons of kyanite gneiss, averaging about 10 percent kyanite, in the northern part of the Burnsville-Swannanoa kyanite belt in North Carolina. The record of kyanite mining at Celo Mountain suggests that the kyanite content may be a little lower than 10 percent. Very large tonnages of kyanite gneiss and schist are also present in the Clarksville district of Habersham and Rabun Counties, Ga., but the rock seems to be of lower grade, possibly averaging between 6 and 8 percent kyanite (Smith, R. W., 1936).

SILLIMANITE

The highest grade sillimanite-bearing rock known in the Southeast is the sillimanite quartzite in several small bodies in the Kings Mountain district, North Carolina–South Carolina. These deposits are estimated to have a total of about 300,000 tons of indicated ore containing about 30 percent sillimanite to a depth of 100 feet. Much of the sillimanite in the district occurs as very fine crystals intimately intergrown with quartz.

The tonnage of sillimanite schist in the belt extending from northeast Georgia through South Carolina into North Carolina is enormous, but most of this material must contain less than 10 percent sillimanite. Furthermore, much of the sillimanite is fine grained and intimately mixed with mica, so that concentration of the sillimanite is difficult and uneconomic at present. Some of the best sillimanite schist is in Hart and Elbert Counties, Ga.; Teague (1950, p. 787) estimated that there are reserves of over 4 million tons of schist, containing about 10 percent sillimanite, on several adjoining properties in Hart County.

ANDALUSITE

The andalusite-pyrophyllite deposits of North Carolina and South Carolina have been discovered so recently that there is not enough information on which to make an estimate of reserves. The larger deposits possibly contain a total of between 1 and 2 million tons of inferred ore of unknown grade to a depth of 100 feet.

KYANITE DEPOSITS

VIRGINIA

FARMVILLE DISTRICT, BUCKINGHAM, PRINCE EDWARD, AND CHARLOTTE COUNTIES

The largest and richest deposits of kyanite known in Virginia are in an area about 30 miles long that lies in parts of Buckingham, Prince Edward, and Charlotte Counties (fig. 27). This area of kyanite deposits is here called the Farmville district after the principal town in the region, which lies on the east edge of the district. Farmville is near the center of the Virginia Piedmont, about 55 miles west of Richmond and Petersburg, and 40 miles east of Lynchburg. Farming and lumbering are the principal occupations. Kyanite is mined at Baker Mountain in the western part of the district and at Willis Mountain in the northern part of the district.

The first modern investigation of the geology of the region was made by Taber (1913), who worked in the James River gold district just north of, and including the northern part of, the kyanite district. Roberts (1928) studied the Triassic rocks here during his work on the Triassic basins of Virginia. Jonas (1932) included the kyanite district in her geologic reconnaissance of a large area in the central Virginia Piedmont. A description of the kyanite deposits by Watkins (1932) accompanies the geologic account by Jonas. The Dillwyn quadrangle (which includes the northernmost part of the area shown on plate 2) and a large area adjoining

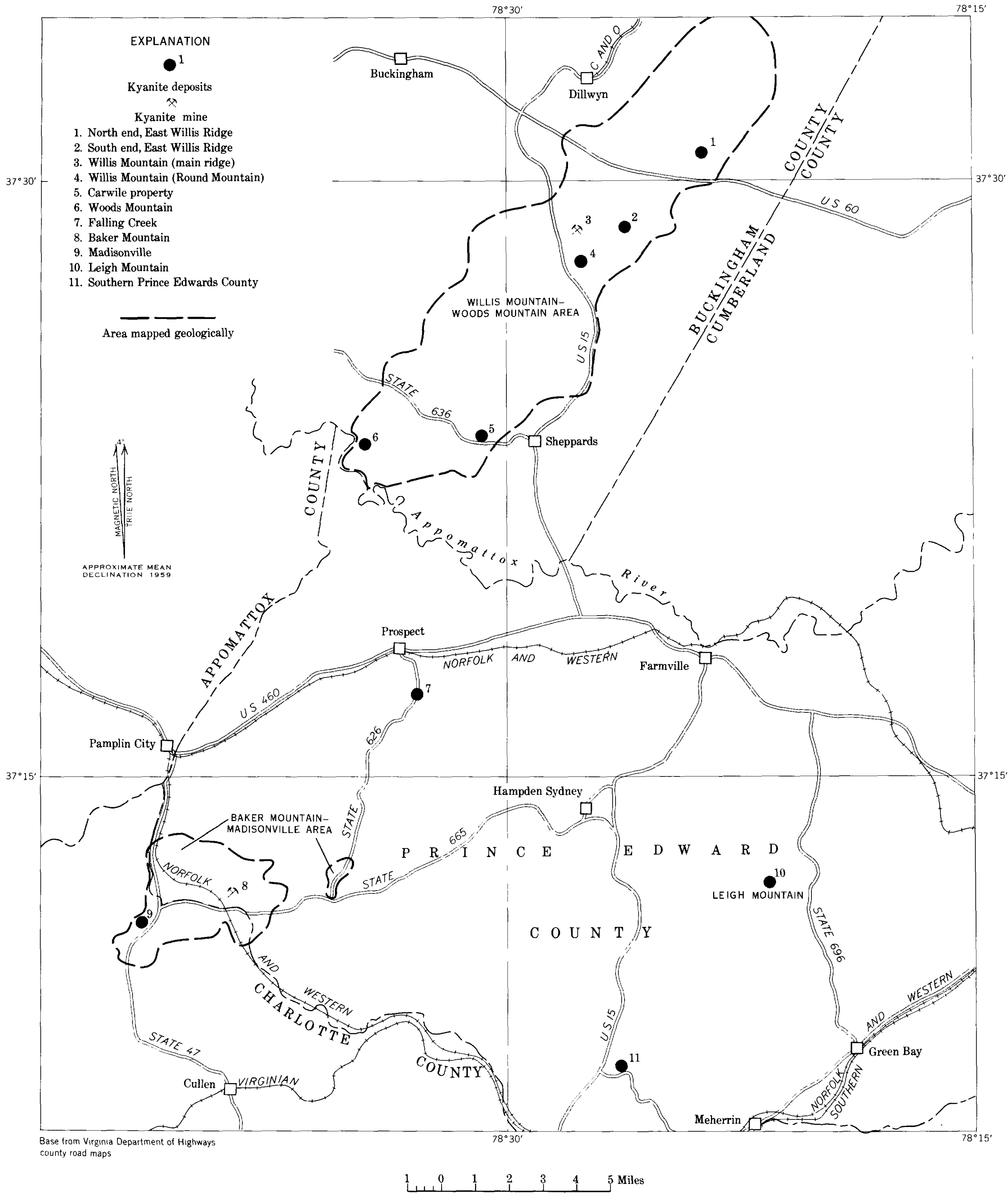


Figure 27.—Index map of kyanite deposits in Farmville district, Buckingham, Charlotte, and Prince Edward Counties, Va.

to the west were recently mapped by Brown and Sunderman (1954).

GENERAL GEOLOGY

The principal rocks in this part of the Piedmont metamorphic belt include several varieties of mica schist and gneiss, hornblende gneiss, and kyanite quartzite, all of probable Precambrian age. Pegmatites and quartz veins are abundant. Bodies of granite occur to the north and east but not in the vicinity of the kyanite deposits. Slate of Ordovician age occurs in a narrow north-trending syncline at Arvonia, a few miles north of the district; the southern end of this syncline may extend into the mapped area. Conglomerate, sandstone, shale, and coal beds of Triassic age occur in a basin about 15 miles long just east of the northern part of the mapped area. Diabase dikes of Triassic age cut all rock formations in the region.

The rocks of pre-Triassic age have been highly deformed and metamorphosed. The trends of the rock formations and the foliation are variable because of complex folding, but in general lie between north and east. The grade of metamorphism is uniform, and belongs to the amphibolite facies (Turner, 1948, p. 76–88), as exemplified by such assemblages as biotite-oligoclase-quartz (with epidote-garnet in places) and hornblende-oligoclase or andesine-quartz (with biotite-epidote-garnet locally).

Erosion since Triassic time has produced a gently rolling surface and deep weathering of the underlying rocks. The highly resistant beds of kyanite quartzite form ridges and knobs (Willis Mountain and neighboring ridges, and Woods, Baker, and Leigh Mountains) that rise 100 to 500 feet above the general peneplain surface.

ROCK TYPES

STRATIGRAPHY

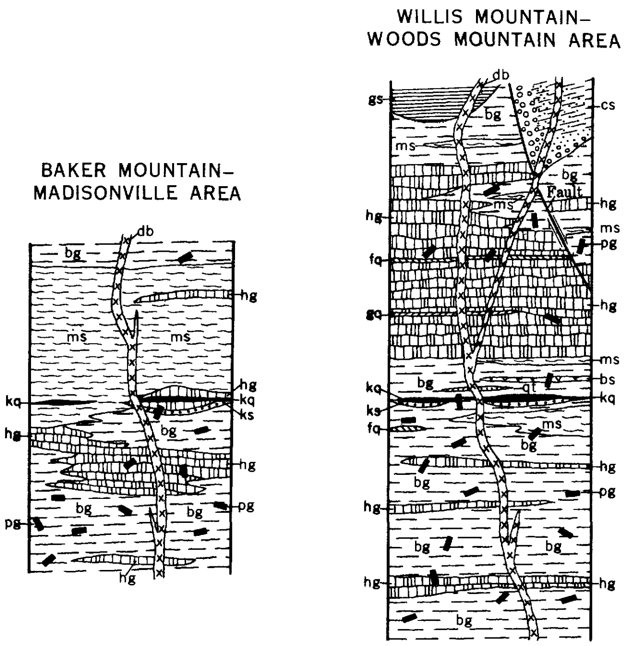
The dominant rocks in the mapped area are biotite gneiss, hornblende gneiss, and muscovite-quartz schist (pls. 2, 3). Kyanite quartzite is a distinctive rock that forms conspicuous outcrops but underlies only a small part of the entire district. The thickness of kyanite quartzite is less than 40 feet at most places, and exceeds 50 feet only at Willis and Baker Mountains. Garnetiferous kyanite schist is exposed beneath kyanite quartzite at several localities. Thinner and less extensive rock units in the metamorphic series are quartzite, ferruginous quartz rock, and garnet-quartz rock. These rocks are probably late Precambrian.

The graphitic schist exposed in the headwaters of Whispering Creek (pl. 2) probably is in the southern extension of the syncline of Arvonia slate of Late Ordovician age. The Ordovician age for the Arvonia slate was originally assigned to fossils found in one of the slate quarries at Arvonia (Darton, 1892; Watson and Powell, 1911); Stose and Stose (1948) have recently questioned this age determination, and suggest that these slates may be Silurian.

Igneous rocks intruding the metamorphic series are pegmatite, biotite-quartz syenite, a few thin dikes of aplite, and diabase. Small bodies of pegmatite occur throughout the region; biotite-quartz syenite is known only at three localities at the northern end of the district. The pegmatites and syenite may be Ordovician or later Paleozoic in age. Diabase dikes of Triassic age cut the metamorphic rocks of the mapped area and the Triassic sedimentary rocks to the east. Quartz veins are widely distributed in the metamorphic rocks; some veins contain abundant tourmaline.

The key to the stratigraphic order of the metamorphic series is found in a large anticline lying east and northeast of Willis Mountain. Biotite gneiss is the major rock type exposed in the core of this anticline (herein called the Whispering Creek anticline); kyanite quartzite lies on both flanks of the fold (pl. 2). This thick sequence of biotite gneiss, containing a few thin layers of hornblende gneiss, is evidently older than the kyanite quartzite. Biotite gneiss also lies beneath kyanite quartzite in an anticline at Woods Mountain, and is exposed to the north of (and stratigraphically beneath?) kyanite quartzite at Baker Mountain (pl. 3). In the Whispering Creek anticline, a thin sequence of biotite gneiss lies just above the kyanite quartzite, and is overlain by a thick series of hornblende gneiss. In the anticline at Woods Mountain, hornblende gneiss appears to lie directly above kyanite quartzite. In the Baker Mountain area, the thickest sequence of hornblende gneiss seems to be just below the kyanite quartzite horizon, but some hornblende gneiss lies above the quartzite, and is overlain by muscovite-quartz schist.

The similarity, though not strict identity, of the apparent stratigraphic order in the different parts of the district strongly suggests that the thick series of biotite gneiss is the oldest formation. Kyanite quartzite occurs in the upper part of the biotite gneiss, and is overlain by hornblende gneiss in the Willis Mountain-Woods Mountain area and by muscovite schist in the Baker Mountain-Madisonville area. This interpretation of the stratigraphic order is shown diagrammatically in figure 28.



EXPLANATION

Symbol	UNMETAMORPHOSED ROCKS		Age
db	Diabase		TRIASSIC
cs	Red conglomerate, sandstone, and shale with coal beds (exposed just east of area mapped near Willis Mountain)		TRIASSIC
	UNCONFORMITY		
pg	Pegmatite		ORDOVICIAN(?) OR YOUNGER
bs	Biotite-quartz syenite		ORDOVICIAN(?) OR YOUNGER
	METAMORPHOSED ROCKS		
	Present character	Probable original nature	
gs	Graphitic schist	Siliceous black shale	ORDOVICIAN(?)
	UNCONFORMITY		
gq	Garnet-quartz rock with abundant amphibole (anthophyllite, actinolite)	Thin layers of sandy and clayey dolomite in basaltic flows	PRECAMBRIAN(?)
fq	Ferruginous quartz rock (contains magnetite and hematite)	Ferruginous chert beds in basaltic flows	PRECAMBRIAN(?)
hg	Hornblende gneiss and schist, commonly garnetiferous	Basaltic or andesitic lava flows	PRECAMBRIAN(?)
qt	Quartzite	Sandstone	PRECAMBRIAN(?)
kq	Kyanite quartzite	Clay-bearing sandstone	PRECAMBRIAN(?)
ks	Kyanite-quartz-mica schist	Shale with high clay content	PRECAMBRIAN(?)
ms	Muscovite-quartz schist	Shale, or silicic volcanic rocks	PRECAMBRIAN(?)
bg	Biotite-quartz-feldspar gneiss, commonly garnetiferous	Graywacke	PRECAMBRIAN(?)

FIGURE 28.—Diagrammatic sections of sequence of formations in the Farmville district, Virginia.

The chemical composition of the biotite gneiss (discussed below) suggests that the parent rock was probably a graywacke (Pettijohn, 1949, p. 250). The character of the hornblende gneiss indicates that it was a basaltic or andesitic lava poured out at irregular intervals during deposition of the thick series of graywacke. The distribution pattern of the kyanite quartzite is that of a folded sedimentary formation; it was probably originally a clay-bearing sandstone.

The biotite gneiss closely resembles and is possibly correlative with the Lynchburg gneiss of Precambrian(?) age, which is widely distributed in a northeast-trending belt about 30 miles to the west (Furcron, 1935; Jonas and Stose, 1939; Brown and Sunderman, 1954; Espenshade, 1954). The hornblende gneiss may be equivalent to the basalt flows of the Catoctin formation occurring above the Lynchburg gneiss on the flanks of the Catoctin-Blue Ridge anticlinorium. The Catoctin may be late Precambrian or early Cambrian in age (Bloomer and Werner, 1955; Reed, 1955). No rocks similar to the kyanite quartzite are known in the Lynchburg gneiss or Catoctin formation.

Most of the areas mapped as biotite gneiss on plates 2 and 3 were mapped by Jonas (1932) as the Wissahickon formation of Precambrian age; however, some areas of biotite gneiss were mapped as granodiorite. Jonas mapped the kyanite quartzite as a separate unit in the Wissahickon formation.

BIOTITE GNEISS

The biotite gneiss is typically a gray rather fine-grained gneiss made up largely of quartz, feldspar, and tiny flakes of black biotite. The rock generally has a finely banded gneissic structure and a pronounced lineation formed by elongated biotite flakes. At a few localities the minerals are coarse grained and the rock resembles somewhat a granitic gneiss. Coarse gneiss in the core of the Whispering Creek anticline, about 3 miles southeast of Dillwyn, was considered by Taber (1913, p. 80–82) to be granite and was mapped as granodiorite by Jonas (1932, pl. 2). Chemical and spectrochemical analyses of two samples of the biotite gneiss are given in table 6. Plagioclase, whose composition is generally about An_{20-30}, is the most abundant feldspar and the only variety present in some of the specimens examined. Microcline also occurs in some of the rock; it is in both of the analyzed specimens (table 6). Biotite is an abundant mineral; in some places it is altered slightly to chlorite. Epidote is commonly associated with biotite; it is an abundant constituent in specimen VPE 102, containing 4.31 percent CaO (table 6), but is absent in specimen VB 118, containing 1.91 percent CaO. Garnet, in small crystals 1 to 2 mm across, is present in much of the gneiss. Muscovite is rather common, and hornblende is found in small amounts in some places. Minor accessory minerals are calcite, apatite, pyrite, sphene, rutile, and zircon.

Biotite gneiss is widely exposed in the region. The greatest thickness of biotite gneiss lies beneath the kyanite quartzite, as in the core of the Whispering Creek anticline, at Woods Mountain, and north of Baker Mountain. Biotite gneiss also occurs at several horizons above the kyanite quartzite. The biotite gneiss is probably a metamorphosed sedimentary rock because it seems to occur most abundantly at a definite stratigraphic position and because it nowhere shows intrusive relations. Its chemical composition suggests that it was originally graywacke.

MUSCOVITE-QUARTZ SCHIST AND GNEISS

Muscovite-quartz schist and gneiss are commonly light gray and rather coarse grained; the muscovite flakes are 3 mm or larger. Plagioclase (An_{5-15}) and microcline are present in some of the more gneissic varieties. A little garnet and kyanite are found at some localities. The more common accessory minerals are tourmaline, magnetite, pyrite, apatite, and zircon. The rock is well foliated; elongated muscovite flakes are arranged in linear orientation.

Muscovite-quartz schist and gneiss are exposed most extensively in the Baker Mountain-Madisonville area (pl. 3) to the south of, and structurally above (as well as stratigraphically above?), the kyanite quartzite. Thin layers of muscovite schist and gneiss are interbedded in the thick biotite gneiss series in the Willis Mountain-Woods Mountain area. The muscovite-quartz schists were probably shales or silicic volcanic rocks originally.

KYANITE SCHIST

Garnetiferous mica schist containing about 5 percent kyanite is exposed beneath kyanite quartzite at the south end of Willis Mountain and east of the Baker Mountain kyanite deposit. The foliation of the schist is closely crinkled, and kyanite, biotite, and muscovite are arranged in linear orientation parallel to the crinkles. Quartz and plagioclase (generally An_{25-35}) are the other essential constituents. Biotite is replaced to a minor extent by chlorite. A little staurolite occurs locally. Kyanite schist may be rather widespread beneath kyanite quartzite in the region, but exposures are few. Ledges of similar kyanite-bearing schist are exposed along Virginia Highway 626 at Falling Creek, Prince Edward County (fig. 27).

TABLE 6.—*Chemical and spectrochemical analyses of biotite gneiss and hornblende gneiss from Farmville district, Virginia*

Chemical analyses

[L. D. Trumbull, analyst]

	Biotite-quartz-feldspar gneiss		Garnet-hornblende gneiss	
	VPE 102	VB 118	VB 111	VB 112
SiO_2	64.85	68.06	50.45	51.66
Al_2O_3	14.86	14.54	15.19	15.27
Fe_2O_3	2.31	.91	3.63	5.39
FeO	3.70	3.92	8.79	7.16
MgO	2.03	2.53	5.49	3.90
CaO	4.31	1.91	8.58	12.01
Na_2O	3.44	3.02	3.98	1.58
K_2O	2.58	3.07	.10	.08
H_2O-	.07	.08	.05	.04
H_2O+	.84	1.02	1.11	1.40
TiO_2	.68	.58	1.68	1.11
CO_2	.01	.00	.39	.01
P_2O_5	.14	.13	.16	.13
F	.04	.05	.03	.01
MnO	.14	.09	.25	.31
Total	100.00	99.91	99.88	100.06
Less O for F	.02	.02	.01	.00
Total	99.98	99.89	99.87	100.06

Spectrochemical analyses

[P. R. Barnett, analyst. Zeros in unit colum signify that the elements were not detected; sensitivity limits for these elements are: B, 0.003; La, 0.005; Mo, 0.0001; and Zn 0.01. Elements not detected in any of the samples, together with their sensitivity limits, are: Ag, 0.0005; As, 0.05; Au, 0.003; Be, 0.0001; Bi, 0.001; Cd, 0.005; Ge, 0.0005; In, 0.001; Nb, 0.001; Pt, 0.003; Sb, 0.01; Sn, 0.001; Ta, 0.05; Th, 0.05; Tl, 0.01; U, 0.05; and W, 0.01]

	VPE 102	VB 118	VB 111	VB 112
B	0	0	0	0.001
Ba	.09	.07	.005	.002
Co	.002	.001	.003	.004
Cr	.0008	.002	.003	.0005
Cu	.0006	.0007	.004	.002
Ga	.002	.001	.002	.002
La	.005	.003	0	0
Mo	0	.0006	0	0
Ni	.0004	.0009	.002	.001
Pb	.002	.001	.001	.002
Sc	.004	.0007	.009	.008
Sr	.2	.1	.1	.3
V	.02	.008	.05	.07
Y	.007	.004	.01	.006
Yb	.0005	.0004	.0007	.0005
Zn	.01	0	.03	.02
Zr	.02	.02	.01	.005

Location of samples:
- VPE 102, Lab. No. 53-831SCD. Outcrop in stream about 1 mile east of Baker Mountain, Prince Edward County, Va.
- VB 118, Lab. No. 53-832SCD. Large ledges just east of Willis River, 2 miles N. 31° W. from Curdsville, Buckingham County, Va.
- VB 111, Lab. No. 53-833SCD. Medium-grained variety of garnet-hornblende gneiss from outcrop just below Arcanum dam on Willis River, Buckingham County, Va.
- VB 112, Lab. No. 53-834SCD. Fine-grained variety of garnet-hornblende gneiss from outcrop just below Arcanum dam on Willis River, Buckingham County, Va.

KYANITE QUARTZITE

The kyanite quartzite is typically a medium- to coarse-grained light-gray gneissic rock made up mainly of quartz and kyanite. The kyanite crystals generally lie within the foliation planes, and commonly have a linear orientation parallel to fold axes. In rocks with very pronounced gneissic structure, kyanite and quartz are segregated into thin layers. The kyanite crystals are commonly several centimeters long and white to light gray, though bright-blue kyanite occurs at Baker Mountain and vicinity. The kyanite content varies considerably, but is generally between 15 and 30 percent. Chemical and mineral analyses of a composite sample of kyanite quartzite taken from drill core at Willis Mountain are given in table 3.

A few percent of mica and pyrite are commonly present. Muscovite is so abundant in places that the rock becomes a kyanite-quartz-muscovite schist. Two varieties of muscovite occur: a common white variety found at Willis Mountain and most of the other localities, and a less abundant bright-green chromian muscovite that is found at Baker Mountain and near Madisonville (table 4). Small amounts of the sodium mica paragonite and the calcium mica margarite are found together in an outcrop along Willis River to the southwest of Willis Mountain (table 4). Disseminated pyrite occurs in more than half of the samples of unweathered rock that were examined; much of the weathered rock has leached cavities and limonite stains that indicate the former presence of pyrite.

Rutile is one of the most persistent accessory minerals, generally occurring in amounts of less than 1 percent as small grains disseminated through kyanite and quartz. The occurrence of rutile with kyanite and the alteration of kyanite to mica in the kyanite quartzite deposits near Madisonville have been described by Watson and Watkins (1911); see also figure 10. Less common accessory minerals (found in 10 to 20 percent of the thin sections examined) are topaz, apatite, and zircon. Topaz, in small rounded grains about 0.2 mm across, is the most abundant of these, but it seldom exceeds 1 percent of the rock. Rare accessories (found in very small amounts in less than 5 percent of the thin sections examined) are diaspore, corundum, barite, spinel, garnet, and magnetite.

Very small amounts of clay of probable hydrothermal origin are present in some of the kyanite quartzite from Willis Mountain. The clay is generally visible only by microscopic examination but is apparent to the naked eye in a few sections of drill core. Clay in stringers a few millimeters thick has been identified as dickite, whereas clay that replaced kyanite crystals adjacent to the dickite stringers, was found to be kaolinite.[5] In the highly weathered kyanite quartzite at Baker Mountain, clay of probable supergene origin is abundant. It has been identified as kaolinite and halloysite and also mixtures of these two minerals.

Coarse, massive kyanite occurs in small elongated bodies that range from a few inches to 90 feet in length in a zone about 1,000 feet long in the kyanite quartzite at Willis Mountain. Kyanite makes up 90 percent or more of the rock; quartz and muscovite are the principal accessory minerals (fig. 7). Smaller aggregates of similar coarse kyanite are scattered through some of the other kyanite quartzite deposits.

The principal deposits of kyanite quartzite in the region occur at Willis Mountain and vicinity and at Woods Mountain in Buckingham County, at Baker and Leigh Mountains in Prince Edward County, and near Madisonville in Charlotte County (fig. 27, pls. 2, 3). Thickness of the kyanite quartzite layers ranges from a few feet to several hundred feet; the layers are thickest where highly folded, as at Willis Mountain. Barren granular quartz forms layers that are 10 to 20 feet thick in kyanite quartzite in some localities, particularly at Woods Mountain.

The kyanite quartzite probably is in the same stratigraphic position throughout the region—in the upper part of the thick series of biotite gneiss and in rather close association with hornblende gneiss. The parent rock of the kyanite quartzite probably was a clay-bearing sandstone.

HORNBLENDE GNEISS AND SCHIST

Hornblende gneiss and schist exhibit considerable variety, ranging from very fine grained dark greenish-black well-foliated rock to extremely coarse massive amphibolite; it is generally fine to medium grained, and has good foliation and lineation. Hornblende and plagioclase (whose composition is generally in the range An_{15-40}) are the essential constituents; quartz is generally present also. Biotite, epidote, and garnet are commonly present. Minor partial alteration of hornblende to chlorite is rather widespread; hornblende is partly altered to pale-green or colorless amphibole (probably tremolite or actinolite) at a few places. Accessory minerals include the opaques (probably ilmenite in most places), apatite, rutile, sphene, and calcite. Scapo-

[5] The clay minerals have been identified from X-ray determinations by F. A. Hildebrand and electron microscope examinations by C. P. Davis and E. J. Dwornik.

lite was found in hornblende-bearing rocks at two localities—just east of Woods Mountain and at the copper prospect on Round Mountain. Fine-grained bright-green chlorite-actinolite schist with talc(?) was found in a belt about 1 mile long extending southwest from Willis Mountain and also at 2 localities near Baker Mountain. Layers rich in epidote and quartz occur at various places, especially in hornblende gneiss several miles east of Woods Mountain.

In the Baker Mountain-Madisonville area the thickest series of hornblende gneiss occurs between the thick series of biotite gneiss and muscovite-quartz schist and with kyanite quartzite at the same stratigraphic position (pl. 3). The hornblende gneiss and schist in this area are typically very fine grained, and have strong lineation formed by alinement of the hornblende needles. Anthophyllite is the major amphibole in coarse garnet-amphibole gneiss exposed about 1½ miles northeast of Darlington Heights.

Much of the area between Willis Mountain and Woods Mountain is underlain by hornblende gneiss, which appears to occur above the horizon of the kyanite quartzite; thin layers of hornblende gneiss are also associated with biotite gneiss in the center of the Whispering Creek anticline (pl. 2). The hornblende gneiss is particularly well exposed along the stream valleys. One of the best exposures is on Willis River just below the old dam at Arcanum. Here layers of very fine grained garnetiferous hornblende gneiss alternate with layers of medium-grained gneiss in crumpled folds plunging 10° to 15° to the northeast. Chemical and spectrochemical analyses of a sample of medium-grained hornblende gneiss and a sample of fine-grained gneiss from this locality are given in table 6. Plagioclase has a composition of about An_{20} in VB 111 and nearly An_{30} in VB 112. Epidote is abundant in VB 112 and absent in VB 111; a little calcite replaces the hornblende in VB 111. Very coarse massive amphibolite is well exposed in a road-metal quarry operated by the State about 0.9 mile north of U.S. Highway 60 at the east edge of this area (pl. 2). Hornblende and plagioclase (An_{25}) are the principal constituents; considerable pale-green chlorite is present, and partly replaces both hornblende and feldspar. A little anthophyllite, garnet, and calcite are found locally.

OTHER QUARTZOSE ROCKS

Thin short layers of barren quartzite occur at the south end of the Whispering Creek anticline and at several other places in the district. Dense blue-gray ferruginous quartz rock—which has disseminations and stringers a few inches thick of magnetite and specular hematite and in some places fine-grained pink to brown manganiferous garnet—forms layers as much as 10 feet thick. Most of these thin layers of iron-manganese-quartz rock are in hornblende gneiss; originally they probably were ferruginous and manganiferous chert beds of the type associated with basaltic lavas in many regions. Coarse crystals of dark-brown staurolite are found in a thin layer of spinel-bearing quartz rock at the north end of the Madisonville kyanite deposit.

Quartzose rock banded with layers of coarse garnet, actinolite, and anthophyllite, containing a few percent of kyanite, sillimanite, and staurolite, occurs at various localities at the north end of the Whispering Creek anticline (pl. 2). The largest deposit underlies Tower Hill, where the rock is exposed over widths of 50 to 75 feet; red garnets, ¼ to ¾ of an inch across, are extremely abundant. The mineral composition indicates that the rock contains considerable lime and magnesia; possibly it was originally a dolomite that contained sand and clay.

GRAPHITIC SCHIST

Fine-grained bluish-gray schist having tightly crinkled cleavage is exposed in the headwaters of Whispering Creek to the west of biotite gneiss (pl. 2). The rock is made up of quartz, fine shreds of muscovite, and pale-brown biotite and is thoroughly permeated with specks and tiny grains of opaque material that is probably graphite. This schist appears less metamorphosed than the nearby biotite and hornblende gneisses because it is fine grained here and has relict bedding where exposed along the road about 1 mile southeast of Dillwyn (locality not shown on pl. 2). Since it lies south of the trend of the Arvonia syncline, it is probably equivalent to the Arvonia slate of Ordovician age. A few miles north of Dillwyn (and just west of the mapped area), fine-grained fissile quartz-chlorite-muscovite schist, containing less graphite and a little kyanite, is exposed for a distance of several miles; this schist also seems to be in the Arvonia syncline. The blue-gray siliceous graphite schist closely resembles the siliceous graphite schist member of the Archer Creek formation of probable Paleozoic age in the James River Valley, about 25 miles to the west (Espenshade, 1954).

It could not be determined within the mapped area whether the graphitic schist is in depositional contact or in fault contact with the presumably older biotite gneiss; the contact is not exposed along Whispering Creek. According to Taber (1913), the basal beds of the Ordovician consist of a thin bed of conglomerate containing pebbles of schist, quartzite, and vein quartz, overlain by a few feet of quartzite. Conglomerate resting on granite is exposed in the railroad cut half a mile south of Carysbrook, about 22 miles northeast of Dillwyn, on the north side of the James River. He also describes conglomerate near Penlan, Va. (outside the mapped area), about 9½ miles northeast of Dillwyn. Stose and Stose (1948) describe the occurrence of conglomerate beds at the base of the Arvonia slate at several other localities. Apparently the Arvonia slate rests unconformably on the older rocks at most places in the region.

BIOTITE-QUARTZ SYENITE AND APLITE

Biotite-quartz syenite is a tan to gray fine- to medium-grained massive granitic rock. Microscopic examination of 2 thin sections shows the syenite to contain about 75 percent potassium feldspar (orthoclase in 1 specimen, microcline in the other), about 10 percent each of biotite and quartz, and considerable apatite and titanium minerals (rutile and leucoxene(?) in 1 specimen, about 5 percent sphene in the other), and a little zircon. In thin section the syenite shows a typical granitic texture and a definite elongation of the feldspars; however, no foliation is evident in the outcrops. Coarse granodiorite with plagioclase (An_{25}) and more quartz than the syenite accompanies the syenite in the northernmost exposure.

The syenite has a very restricted distribution, being known at only three localities at the northern end of the Whispering Creek anticline (pl. 2). The syenite exposures are found at nearly the same stratigraphic position at each place, that is, in biotite gneiss just below the thick series of hornblende gneiss. The northernmost exposure is several hundred feet wide, but the other 2 are only 20 to 30 feet wide. The syenite is unmetamorphosed and probably was intruded locally as thin sills in the very late stages of folding and metamorphism. Pegmatite cuts syenite in the large northern exposure.

Fine-grained gray aplite in dikes less than 1 foot thick cuts biotite gneiss at 2 places near Baker Mountain: in the railroad cut 0.9 mile south of the Baker Mountain opencut and in a streambed just south of Virginia Highway 665 at a point about half a mile east of the junction of Virginia Highways 665 and 671.

PEGMATITES AND QUARTZ VEINS

Pegmatite lenses ranging from a few inches long to bodies 10 feet thick and more than 150 feet long are common throughout the region. They are particularly abundant in the large areas of biotite gneiss in the core of the Whispering Creek anticline and north of the Baker Mountain kyanite deposit. The essential minerals in the pegmatites are quartz, plagioclase (An_{10-35}), microcline at some places, and muscovite; tourmaline and garnet are minor accessories. Many of the smaller lenses and some of the larger ones are conformable to foliation of the wall rock; some bodies occupy cross joints. The pegmatites lack gneissic structure, and evidently were emplaced late in, or following, the last period of strong deformation.

Quartz veins, generally a few inches to a few feet in thickness, are very numerous in the metamorphic rocks. Small stringers of kyanite are present in a few of the quartz veins that cut kyanite quartzite, but kyanite is an extremely rare constituent in quartz veins in the other varieties of metamorphic rocks. Black tourmaline is an abundant mineral in some quartz veins, particularly in veins in biotite gneiss in the Whispering Creek anticline and in the vicinity of Woods Mountain. Tourmaline-bearing veins are most common in the areas of abundant pegmatite bodies. Tourmaline occurs in the following ways: (a) Slender crystals as much as 2 inches long (in places broken) in quartz, (b) massive aggregates of black tourmaline crystals that resemble coal, and (c) extremely fine grained tourmaline crystals arranged in closely spaced layers (about 0.01 in. thick) in quartz. Tourmaline in this last variety may have been formed along shear planes.

DIABASE

Diabase dikes, ranging in width from a few feet to about 200 feet and trending a little west of north, cut the metamorphic rocks. The diabase in the wider dikes is coarse grained. It is composed of laboradorite (about An_{60}) laths with interstitial augite in ophitic relationship and of olivine that is partly altered to antigorite; pyrite and magnetite are opaque accessory minerals. The texture of diabase in narrow dikes and near the contacts of the wide dikes is very fine to fine grained. The diabase dikes are considered as Triassic in age because they are identical in character with diabase dikes of known Triassic age that are intruded into Triassic sedimantary rocks at many places in the Piedmont. Identical diabase dikes cut the sedimentary rocks in the Triassic basins just east of the mapped area and southeast of Willis Mountain (Jonas, 1932).

STRUCTURE

The metamorphic rocks have been highly deformed into folds of varying complexity and trends. Interpretation of the geologic structure is handicapped by the scarcity of distinctive rock units of recognizable stratigraphic position. Kyanite quartzite is the best mapping unit because it occurs in persistent layers that seem to be restricted to the upper part of the thick series of biotite gneiss, and because it is highly resistant to weathering and yields good outcrops and abundant float. Layers of other varieties of quartzose rock (ferruginous quartzite and garnet-quartz rock) are persistent enough in a few places to be useful map units.

The major folds revealed by the outcrop patterns of kyanite quartzite are the large Whispering Creek anticline and the complex folds at Woods Mountain and Madisonville, and possibly Baker Mountain. The Whispering Creek anticline is the dominant structural feature in the northern part of the district. It extends N. 40° E. for about 9 miles as an asymmetric anticline whose east limb dips about 45° E., and west limb stands nearly vertically (pl. 2). The anticlinal structure may extend about 3 miles south of Round Mountain as a tight recumbent anticline with minor folds. A syncline and tight minor folds occur on the west limb of the anticline.

At Woods Mountain, the outcrop pattern of the kyanite quartzite indicates a recumbent anticline whose compressed limbs have been folded into several minor folds that plunge gently northeast (pl. 2). A complex recumbent fold in kyanite quartzite occurs at Madisonville (pl. 3). The structure at Baker Mountain is not clear; kyanite quartzite there may be on the limb or crest of a tight recumbent anticline. Kyanite quartzite at Leigh Mountain (fig. 34) has close drag folding, but the overall structure is not clear; it may be a syncline.

The structural features are conjectural in the extensive areas of biotite and hornblende gneisses where kyanite quartzite is absent. Several complexly deformed recumbent folds are inferred in the area between Woods and Willis Mountains; these inferences are based on rather uncertain stratigraphic interpretations.

It is probable that the area of graphitic schist lying 1 to 2 miles south of Dillwyn (pl. 2) is in the extension of the syncline that contains the Arvonia slate of Ordovician age (p. 40). If so, this syncline extends for a distance of at least 25 miles (Jonas, 1932, pl. 2); the Whispering Creek anticline lies just east of the southern end of the syncline.

Faults have not been recognized with certainty in the area. However, it is most probable that the severe deformation of these rocks was accompanied by thrust faulting that is not evident because of the scarcity of key mapping beds. Two faults are inferred just west of the south end of the Whispering Creek anticline. A fault may also be present about 5 miles farther northeast along the strike, where hornblende and biotite gneisses with fine-grained mylonitic texture and elongated breccia(?) fragments are exposed along the eastern tributary of Hatcher Creek, just southwest of Tower Hill (pl. 2). Normal faults commonly occur on one or more borders of the Triassic basins in the Piedmont province, and Jonas (1932) shows such faults along the west sides of the Triassic sedimentary basins in this region east and southeast of Willis Mountain (east of pl. 2). Normal faults have not been recognized in the metamorphic rocks in the mapped area, but they may be present.

The trends and attitudes of foliation are highly variable. In the areas of broad open folding, foliation follows the trends of the folded units and commonly has low dips; it appears to be conformable, or nearly conformable, to bedding. In areas of tight folding, the foliation has more uniform trends and may dip steeply, as, for example, on the crest of the Woods Mountain anticline; foliation in these areas is about parallel to the axial planes of folds. Two sets of foliation are present in biotite and hornblende gneisses at a few places in the region, particularly just east of the area of graphitic schist.

Joints are best developed in the more massive rocks. Two strong sets of joints are present at Willis Mountain, one being normal to the foliation and dipping nearly vertically and the other having low irregular dips.

Minor structural features, such as small drag folds and lineation, are widely developed. Drag folds are especially well displayed in folded layers of kyanite quartzite. Lineation consists of alined minerals (kyanite, hornblende, and micas), fold axes, fluted surfaces, foliation crinkles, rodlike bodies of quartz, and elongated lenses of massive kyanite (at Willis Mountain). The linear structures generally plunge at low angles, parallel to fold axes (*b* axis); kyanite crystals oriented in the *ac* plane are present in a few small drag folds. Boudinage structure (separated lenticular layers) in kyanite quartzite is exposed in the opencut at Baker Mountain (fig. 29). The thin isolated layers of quartzite and kyanite quartzite at the southern end of the Whispering Creek anticline may be a variety of larger scale boudinage structure.

METAMORPHISM

Except for the graphitic schist south of Dillwyn, the pre-Triassic rocks in the mapped area have all been regionally metamorphosed to about the same degree. The various mineral assemblages were formed in rocks of different chemical composition under conditions of the amphibolite facies; they do not represent mineral zoning caused by important differences in the intensity of metamorphism. Characteristic minerals are kyanite, quartz, biotite, muscovite, garnet, hornblende, epidote, and plagioclase. Less abundant minerals are staurolite, actinolite, tremolite, anthophyllite, talc(?), and chlorite; small amounts of sillimanite are present in a few places, and scapolite was found at two localities.

All these minerals, except possibly scapolite, seem to have been formed primarily from the original constituents of the country rock; however, some transfer of material took place during metamorphism. Microcline porphyroblasts occur in biotite gneiss in some parts of the region, especially in the Baker Mountain-Madisonville area; microcline may have formed by introduced potassium or from potassium that was mobilized during metamorphism.

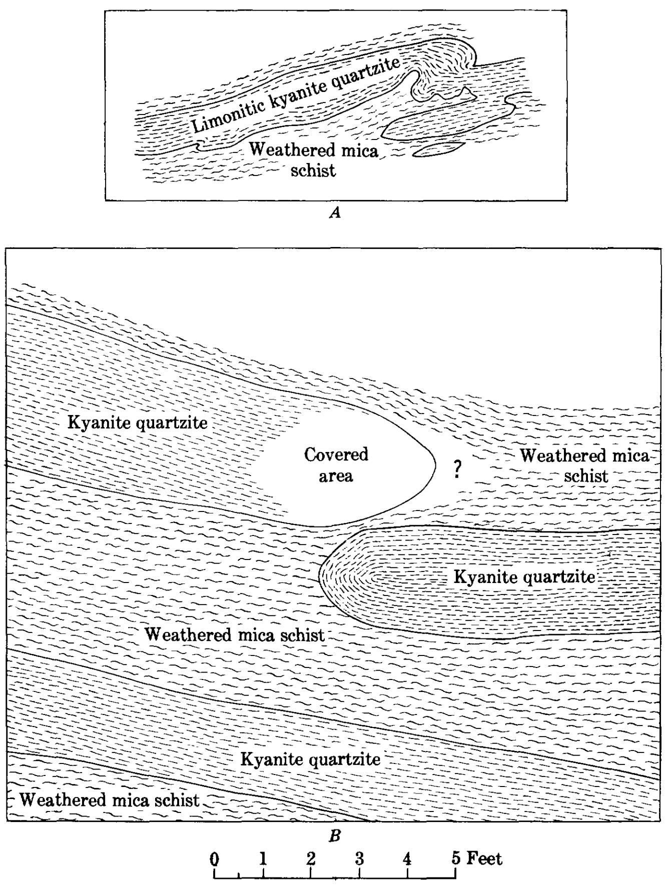


FIGURE 29.—Vertical sections showing folds and boudinage structure in kyanite quartzite in opencut mine of Kyanite Mining Corp., Baker Mountain, Prince Edward County, Va.

The Ordovician(?) rocks that may be in an extension of the Arvonia syncline (the graphitic schist south of Dillwyn and quartz-muscovite schist northeast of Dillwyn) are fine grained and appear less highly metamorphosed than the gneisses in the mapped area to the east. Small crystals of garnet and kyanite are present, however, in some of the quartz-muscovite schist near Dillwyn. Fossiliferous slates are exposed in quarries in the vicinity of Arvonia, 12 miles northeast of Dillwyn.

It seems likely that the peak of regional metamorphism was reached early in the Paleozoic era, before or during deposition of the Ordovician rocks. The Arvonia slate may have been folded and metamorphosed in the declining stages of orogeny.

Some of the metamorphic minerals have undergone minor alteration to minerals that are stable at lower temperatures. The most common alteration of this type is the slight alteration of biotite to chlorite, which is found throughout the region. Hornblende is also partly altered to chlorite but to a lesser extent than biotite. Kyanite is altered to muscovite and clay minerals at a few places. This minor retrogressive metamorphism probably took place through the action of fluids in the declining stages of metamorphism when the temperatures had decreased. Jonas (1932) has advanced the view that profound retrogressive metamorphism took place during late Paleozoic diastrophism; however, we have not found evidence of major retrogressive metamorphism.

GEOLOGIC HISTORY

The geologic history of the region is incompletely understood because time did not permit a study of the belt of Ordovician rocks in the Arvonia syncline just west of the north end of the kyanite district. The relationships between the stratigraphy, structure, and metamorphism of these two groups of rocks is not altogether clear. Present interpretation of the geologic history of the mapped and adjacent areas is as follows:

Late Precambrian(?) and early Paleozoic(?): Deposition of a thick series of graywacke, basalt, shale and (or) silicic volcanic rocks, and extensive thin beds of clayey sandstone. This probably took place during the period of deposition of the Lynchburg gneiss and basalt flows of the Catoctin formation to the west. Deformation and metamorphism,

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followed by uplift and erosion, probably took place in the latter part of the period.

Ordovician(?): Deposition of black shale, ordinary shale, sandstone, and conglomerate. Deformation and metamorphism possibly continued to be active.

Late Ordovician(?) to Permian(?): Declining stages of folding, faulting(?), and regional metamorphism. Intrusion of small bodies of biotite-quartz syenite and pegmatite in the last stages of metamorphism. Formation of gold and sulfide deposits in the area to the northeast. This orogeny may have ended rather early in this time span, followed by erosion.

Triassic: Deposition of thick series of terrestrial clastic sediments with thin beds of coal. Normal faulting and intrusion of diabase dikes.

Post-Triassic: Prolonged period of weathering and erosion with intermittent stages of uplift and stream rejuvenation.

KYANITE DEPOSITS

The principal kyanite deposits in the Farmville district are the deposits of kyanite quartzite at Willis Mountain and vicinity and Woods Mountain in Buckingham County, at Leigh and Baker Mountains in Prince Edward County, and near Madisonville in Charlotte County (fig. 27). Thin layers of kyanite quartzite and kyanite-quartz-mica schist are present at several other places in the area. Kyanite also occurs in garnetiferous biotite schist that lies just beneath the kyanite quartzite at Willis and Baker Mountains; the same type of kyanite-bearing schist is exposed along Virginia Highway 626 at Falling Creek. Kyanite is present in only a few of the numerous quartz veins in the area; it is found in minor amounts in some of the veins cutting kyanite quartzite and in a few veins in schist in the vicinity of Willis Mountain. Kyanite crystals are abundent in soils and alluvium in areas of kyanite-bearing rocks.

Reserves of kyanite quartzite in the Farmville district, minable by opencut methods to depths ranging from 50 to 200 feet, are estimated to be 50 million tons with a kyanite content of between 10 and 30 percent.

Kyanite quartzite is the rock most resistant to weathering in the region, and it characteristically forms good exposures ranging from low ledges (in deposits with low dips or thin beds) to the bold rough crags and cliffs of Willis Mountain. The weathered surfaces of kyanite quartzite are rough and jagged because quartz grains are more easily removed than kyanite. The surfaces of the high ledges and cliffs of Willis and Woods Mountains are etched by pits and furrows resulting from differential weathering along foliation, joints, and linear structures. The rock is commonly heavily stained or impregnated with limonite formed from weathering of pyrite.

WILLIS MOUNTAIN AND VICINITY

In the vicinity of Willis Mountain, kyanite quartzite crops out in two belts on the opposite limbs of the Whispering Creek anticline. On the west limb it forms the prominent ridges of Willis and Round Mountains; on the east limb it forms a lower longer ridge (pl. 2).

The main ridge of Willis Mountain is owned by the Kyanite Mining Corp., operator of the mine at Baker Mountain. The deposit was explored by the U.S. Bureau of Mines in 1949 and 1950 by means of 32 diamond-drill holes and several trenches; the kyanite content of nearly 600 samples was determined by heavy-mineral separation methods (Jones and Eilertsen, 1954, p. 18–37). We logged the drill cores and examined numerous thin sections of selected samples. The Kyanite Mining Corp. began mining near the south end of Willis Mountain in 1957. The flotation mill here is similar to the one at Baker Mountain, and has a daily output of about 120 tons of kyanite concentrates (Herod, 1957, p. 122). The east ridge and the Round Mountain deposit at the south end of the west ridge have not been prospected.

The kyanite quartzite in the southern part of the east limb of the anticline is exposed nearly continuously along a ridge for about 5½ miles and intermittently as thin ledges and float for about 2½ miles farther to the northern end of the anticline. The quartzite on this east limb is thickest in the southern part of the ridge, where the true thickness of the beds ranges between 25 and 40 feet over a distance of about 2 miles. The quartzite is between 5 and 10 feet thick where crossed by U.S. Highway 60, and maintains this thickness for about half a mile to the northeast. For about 1 mile farther northeast, the beds are thicker, and generally average between 30 and 35 feet. The kyanite quartzite loses its continuity at Little Buffalo Creek and exists to the north mainly as short segments a few hundred feet long and less than 5 feet wide. The longest segment, near the north nose of the anticline, is about 2,000 feet long and 5 to 10 feet thick. Sillimanite occurs with kyanite in several of the smaller segments near Hatcher and Buffalo Creeks and in a quartzose layer several feet thick in coarse micaceous kyanite quartzite on Whispering Creek, about three-fourths of a mile southeast of the east ridge.

On the steep west flank of the Whispering Creek anticline, kyanite quartzite is exposed for a distance that is less than half its length of exposure on the east limb, but the outcrop width is considerably wider on the west limb and the ridge is much more prominent. The principal belt of kyanite quartzite on the west extends for about 2½ miles north from the south nose of the anticline and consists of several discontinuous segments (pls. 2, 4). The longest segment of kyanite quartzite forms Willis Mountain, a ridge about 1¼ miles long that rises over 500 feet above the surrounding countryside and makes the most conspicuous landmark in this part of the Virginia Piedmont. Steep cliffs of kyanite quartzite from 100 to 150 feet high form the upper part of the mountain along most of its length; the lower slopes are mantled with talus containing large blocks of kyanite quartzite. Round Mountain, a ridge about 1,500 feet long and having cliffs up to 100 feet high, is formed by a body of kyanite quartzite whose northern end is about one-third of a mile south of Willis Mountain. At the northern end of Round Mountain and the southern end of Willis Mountain kyanite quartzite is exposed in oppositely curved belts formed by a syncline whose axis reverses its direction of plunge between these ridges and plunges gently northward along Willis Mountain and southward along Round Mountain (pl. 2). Kyanite quartzite on the west limb of each syncline is exposed for only short distances, the probable extensions to the north and south being covered by heavy talus from the main ridges. Probably the kyanite quartzite in the west limb of the synclines beneath the talus-covered areas either becomes very thin or is cut out by steep thrust faulting; both inferences are shown on plate 2.

There is considerable close folding (fig. 30) on the east limb of the syncline (west limb of the Whispering Creek anticline), and the shapes and widths of the kyanite quartzite exposures on Willis Mountain are probably related to this folding. The hook-shaped segment at the south end of Willis Mountain lies several hundred feet to the west of the main ridge. This offset probably was caused by folding or faulting, or possibly both; north-plunging folds have been assumed here on plate 2, section *A–A′*.

Along the high part of Willis Mountain north of this gap, kyanite quartzite is exposed over widths of between 200 and 300 feet for a distance of about 2,000 feet; this part of the ridge trends N. 5° to 10° E. (pl. 4). For about 3,000 feet farther northeast, the ridge declines gently in elevation, and the quartzite outcrop becomes narrower, ranging be-

FIGURE 30.—Minor folds and pitted weathering in kyanite quartzite near south end of Willis Mountain. View looking north in direction of plunge of fold axes.

tween 100 and 150 feet; the trend of the ridge changes rather abruptly to N. 15° to 20° E. The kyanite quartzite beds in the widest and highest part of the ridge have been thickened considerably by drag folds; such folds may be few or absent in the lower and narrower part of the ridge to the north.

A thin diabase dike has been inferred to cut through the gap between these two segments of kyanite quartzite (pl. 2). This inference is supported by the facts that the gap is about 3,000 feet northwest along the strike from an exposed diabase dike, and that a diabase boulder was found on the west slope of Willis Mountain a few hundred feet below the gap; diabase crops out along a creek about 1 mile northwest from the gap along this trend. Diabase has been exposed on the west side of the gap by recent mining operations.

Short thin bodies of kyanite quartzite and schist, and quartzite that is nearly barren of kyanite, occur on the south nose of the Whispering Creek anticline (pl. 2). These isolated segments may be the remnants of formerly continuous beds that have been thinned and separated by intense folding and shearing. It is possible that the southern end of the anticline extends for about 3 miles south of Round Mountain as a crumpled recumbent anticline (pl. 2).

Linear structures are best developed in the kyanite quartzite on the west flank of the Whispering Creek anticline. They consist of fold axes, alinement of minerals (principally kyanite and muscovite), rod-shaped bodies of massive kyanite and of quartz, and the intersection of foliation with another surface which may be bedding. On the main ridge these structures generally plunge rather uniformly to the northeast, as does the axis of the syncline exposed at the south end of Willis Mountain. The angle of plunge is generally between 10° and 20° NE. in the wide high part of the ridge, and becomes a little steeper, 20° to 30° NE., in the narrow northern part. The crest of the ridge also slopes gently to the northeast. Linear structures on Round Mountain and at the south nose of the Whispering Creek anticline plunge to the south.

Two systems of joints are conspicuous at Willis Mountain; a set of steep joints lying about at right angles to the strike and a set of joints with gentle dips (generally 10° or less) and variable strike. Both sets of joints are about at right angles to the nearly vertical foliation, and, as a result, the kyanite quartzite has weathered into huge rectangular blocks and surfaces (fig. 31).

Quartz veins and pegmatites are found in some abundance in the Willis Mountain area. Quartz occurs as irregular veins cutting the kyanite quartzite; as slender rods, as much as 15 feet long and

FIGURE 31.—View looking north along the west side of Willis Mountain. Rectangular exposures and loose blocks of kyanite quartzite are caused by three strong structures—steep foliation (in direction of view), steep cross joints, and gently dipping bedding or joints.

1 foot in diameter, that plunge gently northward parallel to the linear structures; and as thin layers of coarsely granular quartz, a few millimeters thick, that are formed along foliation planes in the gneissic kyanite quartzite. This latter variety of quartz may have been introduced along innumerable thin foliation planes. The total amount of such introduced quartz may have been on the order of magnitude of 10 to 20 percent of the present volume, and thus could have been an important factor in the formation of the unusual thickness of kyanite quartzite here. Several small bodies of pegmatite occur in kyanite quartzite and schist at the south end of Willis Mountain, and in the saddle between Willis and Round Mountains.

The kyanite quartzite on both limbs of the anticline is composed principally of kyanite and quartz, and has a pronounced gneissic structure. Considerable muscovite occurs in the rock along the flanks and northern end of Willis Mountain and along the northern part of the east ridge. Much of the rock is heavily stained or impregnated with limonite derived from the weathering of pyrite. In the fresh rock of drill cores from Willis Mountain, pyrite is seen to be unevenly distributed (pl. 4, vertical sections of diamond-drill holes); it amounts to several percent in some of the rock, but is virtually absent in places. Small grains of rutile occur through the kyanite quartzite, generally in amounts of about 1 percent. Minute amounts of clay in the form of dickite stringers and kaolinite replacements of kyanite and quartz occur locally, particularly in the vicinity of drill hole 6 (figs. 11, 12). Topaz also occurs locally in aggregates of small grains, but only in a few places does it make up more than 1 percent of the rock. Small grains of pale-yellow sphalerite that fluoresce bright golden are scattered through kyanite quartzite in core from drill hole 30.

The kyanite content of kyanite quartzite that contains small amounts of white mica and of micaceous kyanite quartzite that contains considerable white mica is shown in table 7, which summarizes the results of analyses of drill-core samples taken by Jones and Eilertsen (1954), of the Bureau of Mines. The sample data are arranged into two groups, one from drill holes near the southern part of the mountain and the other from drill holes at the northern end of the mountain. In both areas the kyanite quartzite contains more kyanite than the micaceous kyanite quartzite. Kyanite is more abundant in both rock types at the southern part of Willis Mountain than it is in the rocks at the northern end of the mountain. Analyses of samples from individual holes are summarized below the drill-hole sections on plate 4. These analyses show that the iron content in the samples of kyanite quartzite and micaceous kyanite quartzite at the northern end of the mountain is several times the iron content of samples from the southern part of the mountain. Pyrite is widely distributed through the core from the northern drill holes but is much less abundant in the core from the southern drill holes. The iron in samples of weathered rock (pl. 4) is mostly limonite instead of pyrite.

Chip samples were taken of surface exposures along three lines across the north end of the mountain, above drill holes 26, 27, 28 and 29 (Jones and Eilertsen, 1954, p. 38). These surface samples contain more kyanite than the drill samples (pl. 4), probably because rock rich in kyanite is better exposed than rock lean in kyanite.

TABLE 7.—*Distribution of kyanite in drill-core samples, Willis Mountain, Buckingham County, Va.*

[Analytical data from Jones and Eilersten, 1954, with samples grouped according to dominant rock types as logged by G. H. Espenshade and D. B. Potter]

Range in kyanite content (percent)	Percent of samples (weighted for sample interval) per grade group			
	Southern part of mountain (drill holes 1–25, A–1, A–2)		Northern end of mountain (drill holes 26–30)	
	Kyanite quartzite	Micaceous kyanite quartzite	Kyanite quartzite	Micaceous kyanite quartzite
10–14.9	0.1	8.6	None	25.2
15–19.9	.8	7.4	5.1	20.0
20–24.9	2.7	37.0	6.3	43.1
25–29.9	17.6	28.5	60.5	11.7
30–34.9	54.0	16.9	28.1	
35–39.9	21.3	1.6		
40–44.9	1.6			
45–49.9	.8			
>50	1.1			

A chemical analysis of a composite sample of kyanite quartzite (VB–W) from 5 drill holes at Willis Mountain is given in table 3. The kyanite content of this sample as calculated from the chemical analysis is 43.7 percent; modal analysis of 6 thin sections gave an average content of 44.6 percent kyanite and about 4 percent topaz for this sample.

Along the southern part of the east ridge opposite Willis Mountain, grab samples were collected by us from kyanite quartzite at intervals of 3 to 5 feet stratigraphically across the full thickness of the beds at 3 widely spaced localities; the kyanite content of these composite samples was determined by heavy-mineral separation methods as 35.0, 35.3, and 38.4 percent kyanite. These values are probably somewhat above the average kyanite content of the unweathered rock, because more quartz than kyanite has been removed by differential surface weathering; however, it is evident that kyanite is rather abundant in this part of the east ridge. Topaz amounted to 0.02 percent of one sample and 0.3 percent of another.

A very coarse variety of kyanite quartzite is exposed in a long zone, as much as 30 feet wide, at the base of the west cliff along the wide high part of Willis Mountain (pl. 4). The kyanite forms large prismatic crystals, up to 2 inches long, that commonly lie within the plane of foliation; kyanite crystals in random orientation locally form small knots or lenses a few inches across. The dip of foliation within this zone varies over short distances from a few degrees to nearly vertical. This coarse kyanite quartzite has probably been formed in a zone of tight folding on the west limb of the anticline.

Elongated lenses of massive kyanite occur along the crest and along the east side of the ridge to the north of the gap in Willis Mountain (pl. 4). Light-gray prismatic crystals of kyanite as much as 2 inches long occur in clusters and randomly oriented crystals (fig. 7). Kyanite makes up more than 90 percent of this rock, and is accompanied by a few percent of muscovite and quartz. Rutile grains as large as 1 mm are common, being especially conspicuous between the kyanite crystals; a little diaspore and pyrite are also present. Under the microscope, kyanite and diaspore are seen to be replaced by thin stringers of dickite (fig. 12).

These lenses of massive kyanite are elongated in the form of rodlike shoots a few inches to 90 feet long and as much as 10 feet across. These shoots lie within the foliation and plunge 10° to 15° NE. parallel to the linear structures in the kyanite quartzite. A longitudinal view and cross sections of the large northernmost massive kyanite rod are shown in figure 32. The contact between these aggregates of randomly oriented kyanite and the enclosing gneissic kyanite quartzite is very sharp. Exposures of massive kyanite project above the kyanite quartzite with very rough, jagged surfaces. The zone of massive kyanite rods extends for nearly 1,000 feet in a N. 14° E. direction and plunges between 5° and 10° NE.

The parallelism of the zone and the individual lenses of massive kyanite to linear structures in the country rock and the unoriented nature of the kyanite crystals strongly suggest that the massive kyanite aggregates were formed in sites of low-

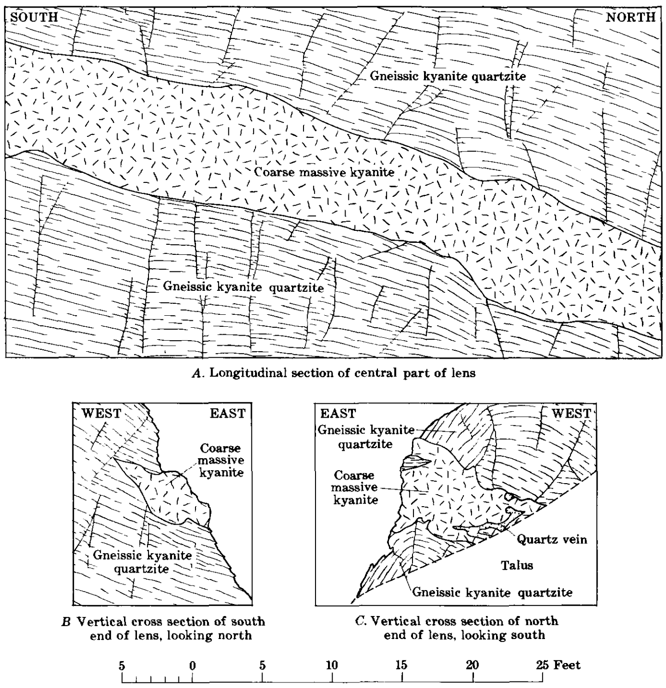


Figure 32.—Longitudinal and vertical cross sections of elongate lens of coarse massive kyanite, about 65 feet west of drill hole 5, east wall of Willis Mountain, Buckingham County, Va.

shearing stress within a zone of tight folding, and perhaps along the axes of minor folds. The formation of the massive kyanite shoots was probably contemporaneous with the development of foliation and the system of gently dipping joints; massive kyanite in layers a few inches thick extends along several of the gently dipping joints.

The massive kyanite of Willis Mountain resembles the kyanite of strategic quality found in Kenya and seems to have similar desirable physical characteristics when processed. Unfortunately, the total tonnage of this variety of kyanite contained in the elongated lenses, and the boulders scattered along the east slope of Willis Mountain, is small.

Garnetiferous quartz-mica-feldspar schist containing about 5 percent kyanite lies beneath the kyanite quartzite. It is exposed at the south end of Willis Mountain and in several prospect trenches on the east slope of the ridge; a more feldspathic variety was cut in drill hole 26 at the north end of the ridge (pl. 4). The thickness and extent of this kyanite schist cannot be determined because of the heavy cover of talus.

Small amounts of kyanite occur in quartz-muscovite schist and in some quartz veins about a mile west of Willis Mountain and a mile east of the eastern ridge. A few percent each of kyanite and sillimanite are present in garnet-actinolite-quartz rock in a narrow belt that extends east from Tower Hill at the north end of the anticline. Somewhat similar garnetiferous rock containing kyanite and sillimanite has been reported near New Canton, about 12 miles northeast of Tower Hill (Taber, 1913, p. 108).

WOODS MOUNTAIN AND VICINITY

Kyanite quartzite forms a ridge over 100 feet high at Woods Mountain, about 9 miles southwest of Willis Mountain. The kyanite quartzite is exposed in an irregular curving pattern which evidently represents a recumbent isoclinal anticline that has been folded into several minor anticlines and synclines that plunge 15° to 20° NE. (pl. 2). The winding course of the Appomattox River just west and south of Woods Mountain closely parallels the outcrop pattern of the kyanite quartzite. In the southern part of the mountain, the two parallel belts of easterly dipping kyanite quartzite are the limbs of the recumbent fold (pl. 2, section *B–B′*); quartzite on the east limb is not so continuous as on the west limb. True thickness of the beds on each limb ranges from about 15 to 40 feet for a distance of about 1½ miles. The quartzite in the crest of the fold is exposed over widths of 20 to 40 feet for a distance of about three-fourths of a mile northeast of the junction of the limbs of the fold. In the outcrops farthest southeast, the quartzite is only a few feet thick. Strong linear structures that plunge 15° to 25° NE. are widely developed; these consist of fold axes, foliation crinkles, fluting in kyanite quartzite and quartz veins, and alinement of kyanite and muscovite.

Small tight folds a fraction of an inch to several feet across are abundant in the foliation of the kyanite quartzite at Woods Mountain. The characteristics of these minor folds suggest that folds of two ages are present, an older group formed in the early stages of anticlinal development (fig. 33*B*, *C*), and a younger group formed during folding of the compressed recumbent anticline (fig. 33*A*, *D*).

Much of the rock is gneissic kyanite quartzite containing thin layers of coarse granular quartz, similar to the rock at Willis Mountain. Some of the rock has abundant large muscovite flakes, and is heavily stained with limonite. Layers of massive coarse barren quartzite, as much as 10 feet thick, are present; this barren quartzite weathers to smooth rounded surfaces in contrast to the very rough surfaces of the kyanite-bearing rock. Grab samples were taken of the kyanite quartzite at intervals of about 3 to 5 feet apart stratigraphically

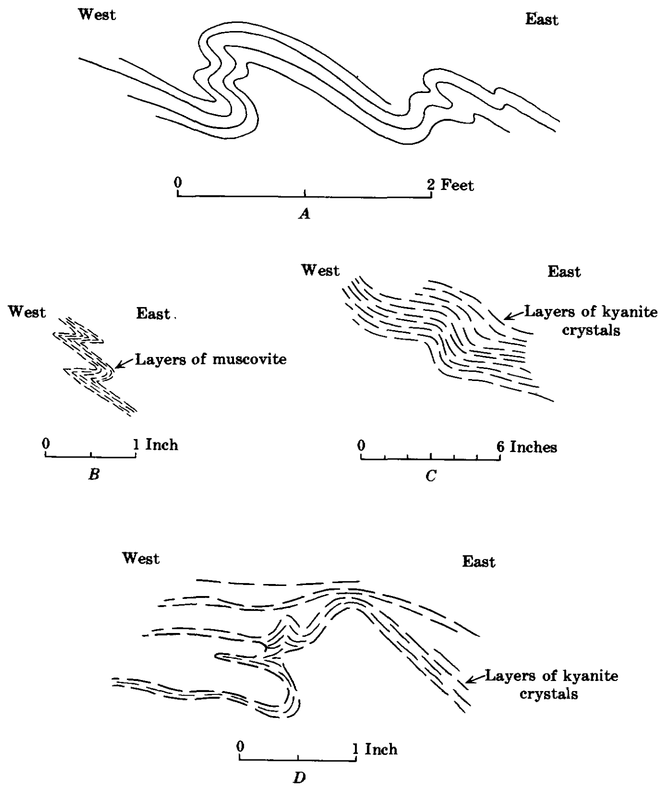


FIGURE 33.—Vertical sections showing drag folds in kyanite quartzite in recumbent anticline of Woods Mountain, Buckingham County, Va.

at 3 localities in the southern half of the ridge. Kyanite content of the composite samples was determined by heavy-mineral separation methods as 7.8, 14.5, and 26.1 percent; 1 sample contained 0.7 percent topaz and another 0.6 percent.

Kyanite quartzite is exposed in low ledges in several arc-shaped outcrops that are 100 to 200 feet long on the Carwile property, about 3 miles east of Woods Mountain and 0.4 mile northwest of the intersection of Virginia Highways 608 and 636. The beds range from 1 to 10 feet in thickness and dip gently eastward; kyanite crystals have a linear orientation plunging down the dip. A few tough, dense rounded boulders of massive kyanite, composed of fine interlaced kyanite crystals and resembling the variety of massive kyanite from India, are found on the roadbank just south of the deposit. Layers of kyanite quartzite and kyanite-quartz-muscovite schist a few hundred feet long and several feet thick occur at several places to the south, northeast, and north of the Carwile deposit (fig. 27). They appear to be at the same stratigraphic position as the Carwile deposit, that is, in biotite gneiss near its contact with hornblende gneiss.

BAKER MOUNTAIN-MADISONVILLE AREA

Kyanite occurs in quartzite at Baker Mountain, Prince Edward County, about 14 miles southwest of Woods Mountain, and also near Madisonville, Charlotte County, about 3 miles southwest of Baker Mountain (pl. 3). Smaller quantities of kyanite are in garnetiferous biotite gneiss at Baker Mountain and vicinity and along Falling Creek, about 8 miles to the northeast (fig. 27).

Kyanite was discovered in the Baker Mountain-Madisonville area by Joel H. Watkins. He began mining kyanite at Baker Mountain with J. F. McLanahan, Jr., in the early 1920's (Hubbell, 1941), and also dug several shallow prospect pits on the James Pugh property at Madisonville. The Baker Mountain mine probably was the first kyanite mine in the Southeast; kyanite was separated from the rock by grinding and tabling (Watkins, 1932). Mining ceased in 1926 following McLanahan's death. The property was acquired by others in 1934, but no further mining was done until 1937, when the Phosphate Recovery Corp. explored the deposit by diamond drilling and installed a flotation mill capable of producing 35 tons of kyanite concentrates daily. The Kyanite Products Corp. operated the mine from 1940 until the end of 1944, when it went out of business. In early 1945 the property was acquired by the Kyanite Minig Corp. which has operated the mine since then. The concentrating plant was rebuilt in 1952 and 1953.

Mining and milling practices, described by Avery (1953b) and Corriveau (1955), are briefly as follows: The ore is mined by power shovel in a large opencut, and trucked several hundred yards to the mill. The feed is reduced to minus 4–inch size by grizzly and jaw crusher, and then most of the clay is removed by log washers. The cleaned material is crushed and ground to about 28–mesh size and a kyanite flotation concentrate made. Considerable limonite accompanies the kyanite in this concentrate; the limonite is converted to magnetic iron oxide by reduction roasting of the concentrate, and the magnetic iron oxide is then removed by electromagnets, yielding a product containing less than three-fourths percent iron. This material is marketed as raw kyanite and mullite (calcined kyanite) in 35–, 48–, 100–, and 200–mesh sizes. Capacity of the plant is about 2,000 tons of kyanite concentrates monthly, produced from nearly 20,000 tons of ore according to Avery (1953b). Corriveau (1955) states that 15,608 tons of kyanite concentrate was recovered from 131,128 tons of ore in 1954. He gives the following data for operations during October 1954:

	Tons per day	*Percent kyanite*
Mined	550	15
Slimes to waste	215	1
Feed to flotation	335	24
Flotation tailings	250	4.4
Flotation concentrates	85	82
Magnetic rejects	20	43
Final concentrate	65	94

Baker Mountain, a low rounded knob rising about 100 feet above the countryside, is capped by kyanite quartzite which crops out in low massive ledges. Although the overall dip of the kyanite quartzite is at low angles to the south, the rock is highly deformed by irregular minor folds whose plunges trend in all directions. In places, layers of kyanite quartzite a few feet thick have been compressed into small recumbent folds or have been separated into lenticular segments (boudinage structure) that are surrounded by schist (fig. 29). Kyanite and muscovite crystals are commonly in linear orientation.

The nature of the major structure at Baker Mountain is by no means clear, but it is possible that the broad curving belt of kyanite quartzite is on the lower limb, or is the compressed crest, of a large recumbent anticline. Features suggesting this structure are the presence of only one belt of kyanite quartzite (the crest of the fold?) to the east of Baker Mountain and two belts of disconnected bodies of kyanite quartzite (the limbs of the fold?) to the west of Baker Mountain. At the west end of the northern belt (about 800 feet west of the diabase dike, pl. 3) small drag folds in the foliation of kyanite quartzite consistently indicate the overturned limb of an anticline.

Kyanite quartzite occurs on the property of James Pugh near Madisonville, Charlotte County, about 3 miles west of Baker Mountain (pl. 3). The quartzite is exposed in low ledges over widths as much as 40 feet. It appears to be in a very complex recumbent fold that has intricate minor folds; the general dip is to the east. The thickest and most persistent belt of kyanite quartzite extends for about half a mile northwest from Virginia Highway 47; it forms low, inconspicuous ridges in places. Considerable exploration would need to be done to determine the underground extent of the kyanite quartzite, its thickness and grade, and the nature of the rock lying between the layers of quartzite. Thin ledges of kyanite quartzite in many outcrops of variable orientation occur about 1½ miles north of the Madisonville deposit, mostly east of Virginia Highway 47; the irregularities of these outcrops are probably due to folding.

The kyanite quartzite is typically a medium- to coarse-grained gneissic rock that generally contains a few percent of muscovite (figs. 3, 10); small grains of rutile are a persistent minor accessory. Much of the rock is heavily coated with limonite; fresh rock usually contains several percent pyrite. Some of the kyanite is white to light gray but bright-blue kyanite crystals, an inch or more in length, are found in parts of the Baker Mountain deposit, near Madisonville, and at several other places. A variety of green muscovite that occurs with this blue kyanite at several places contains a little chromium (table 4); kyanite is replaced by green muscovite at a locality near Madisonville (fig. 10). A few percent of barite and spinel are present in a thin layer of kyanite-quartz rock in the railroad cut about 0.9 mile west of Baker Mountain mine; kyanite occurs in small amounts in very garnetiferous quartz rock about 0.2 mile east of the latter locality.

The kyanite content of the kyanite quartzite of this area varies considerably from place to place. The amount of kyanite in composite grab samples of kyanite quartzite taken from three localities has been calculated from the partial chemical analyses (table 8). It will be noted that the kyanite content decreases progressively from east to west; this change may be purely coincidental and have no geologic significance. It is interesting that the the amount of TiO_2 (presumably all present as rutile) varies directly with the Al_2O_3 content.

TABLE 8.—*Partial chemical analyses and calculated kyanite content of kyanite quartzite from the Baker Mountain area, Prince Edward County, Va.*

[Chemical analyses: W. J. Blake, Jr., analyst]

	VEP-71	VEP-72	VEP-73
Kyanite quartzite samples			
Al_2O_3	23.82	16.92	13.16
Fe_2O_3 (total)	.72	2.81	.69
TiO_2	1.06	.62	.33
P_2O_5	.02	.04	.03
Calculated kyanite content			
Muscovite content[1]	1.8	2.6	2.0
Al_2O_3 available for kyanite [2]	23.13	15.91	12.37
Kyanite content (calculated)	36.6	25.2	19.5

[1] Determined by heavy-mineral separation method.
[2] Total Al_2O_3 — theoretical amount of Al_2O_3 needed for muscovite.

Location of samples:
VPE-71, Lab. No. ID-5113. Composite of grab samples from crescent-shaped belt of kyanite quartzite, about half a mile east of Baker Mountain mine.
VPE-72, Lab. No. ID-5114. Composite of grab samples from belt of kyanite quartzite just west of Norfolk and Western Railway, about half a mile west of Baker Mountain mine.
VPE-73, Lab. No. ID-5115. Composite of grab samples from scattered outcrops of kyanite quartzite just east of Virginia Highway 47, about 2¼ miles west of Baker Mountain mine.

The kyanite quartzite and associated rocks at Baker Mountain have been very highly weathered; crumpled layers of porous limonitic kyanite quartzite as much as 10 feet thick alternate with layers composed largely of clay. Much of the clay is white to gray and mottled with small purplish spots. It has a finely crinkled relict schistosity, contains a little kyanite, muscovite, hematite, and fine rutile, and has small cavities from which probably either garnet or pyrite has been leached. Such clay has been determined by Hildebrand, Davis, and Dwornik to be mainly kaolinite and a minor amount of halloysite. This material has probably been derived from the weathering of a mica-feldspar gneiss or schist having a low to moderate kyanite content. Some fresh feldspathic gneiss was found in drill core (location of hole and depth unknown), and garnetiferous biotite gneiss with a little kyanite and staurolite is exposed beneath kyanite quartzite at several places east of the mine (pl. 3). White to tan massive clays with no evident schistosity, and containing some quartz, muscovite, and kyanite, are also present. One sample of this variety of clay consisted mainly of halloysite and a little kaolinite; in another sample halloysite and kaolinite were mixed in nearly equal proportions. The parent rock of this variety of clay was probably a massive feldspathic rock containing some kyanite, quartz, and mica. No fresh rock of this nature was observed in the vicinity. Pegmatite composed of quartz, feldspar, and muscovite is exposed at some places in the opencuts, but it contains much coarser quartz than the massive clay and has no kyanite; the pegmatite, therefore, could hardly have been the parent rock of the massive clay.

Jonas (1932, pl. 2) shows a body of kyanite quartzite about 2½ miles east of the Baker Mountain mine, but this was not found by us. Garnetiferous mica gneiss containing kyanite is exposed along Virginia Highway 626 at Falling Creek, about 8 miles northeast of Baker Mountain and 1½ miles south of Prospect (fig. 27). Large massive ledges along the road and stream dip gently eastward.

LEIGH MOUNTAIN

Kyanite quartzite occurs at Leigh Mountain, a rounded knob about 200 feet high, about 7 miles southeast of Farmville (fig. 27). The quartzite is exposed in low ledges that make a sinuous pattern of discontinuous outcrops characteristic of closely folded beds. These ledges crop out intermittently over a distance of about 600 feet, and are distributed across a width of about 400 feet on the southwest slope of the knob (fig. 34). The largest outcrop, a triangular area whose sides are more than 100 feet long, appears to be the thickened keel of a syncline that plunges to the northeast. Fold axes and linear structures in other exposures also plunge northeast at angles between 10° and 30°. Many of the ledges are between 5 and 10 feet thick, which is probably the normal thickness of the beds except where thickened by folding. About a mile southwest of Leigh Mountain, thin layers of micaceous kyanite quartzite a few feet thick are exposed along Virginia Highway 628, to the south of a stream.

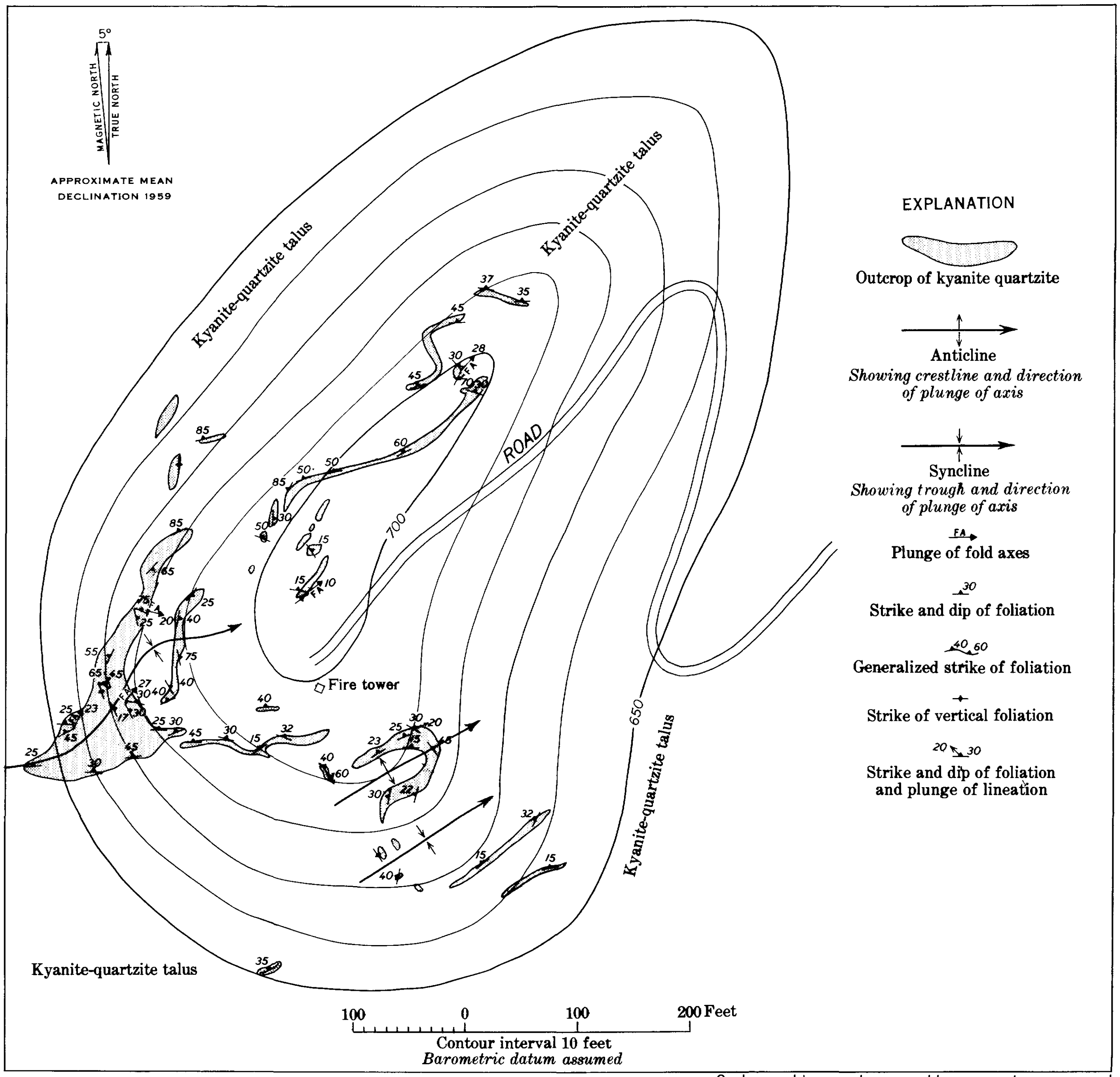
SOUTHERN PRINCE EDWARD COUNTY

In southern Prince Edward County, kyanite-quartz rock occurs about three-fourths of a mile east of U.S. Highway 15, near a large bend in Virginia Highway 634 and along the top of a bluff a few hundred yards to the north (fig. 27). The kyanite-quartz rock, which is very fine grained and light gray, crops out in low ledges less than 5 feet wide. The rock is exposed intermittently for lengths of a few hundred feet in a distance of nearly half a mile. Jonas (1932, pl. 2) shows this body of kyanite quartzite, as well as two other bodies several miles east of here near Meherrin and Green Bay; we did not find kyanite quartzite at these last two localities.

ORIGIN OF KYANITE DEPOSITS

The occurrence of kyanite quartzite and kyanite-garnet-mica schist in persistent layers at a restricted stratigraphic position throughout the Farmville district is regarded as definite evidence that these kyanite-bearing rocks were originally sediments. Nevertheless, there are two possible sources for the aluminum now in the kyanite: the aluminum may have been present in the parent sediment before metamorphism, or it may have been introduced into the sediment during metamorphism. In the first instance, clay-bearing sandstone composed mostly of silica (80 to 90 percent) and alumina (10 to 20 percent) would have been the parent sedimentary rock of the kyanite quartzite, and a high-alumina shale the parent sedimentary rock of the kyanite-garnet-mica schist. The clay could have been derived from the weathering of basalt or other volcanic rocks during a lull in the deposition of graywacke.

On the other hand, if all the aluminum had been introduced into the sedimentary rock (possibly pure quartz sandstone) by hydrothermal solutions during metamorphism, it may have come either from an



Geology and topography mapped by pace and compass and barometer by G. H. Espenshade, October, 1952

FIGURE 34.—Geologic map of Leigh Mountain, Prince Edward County, Va.

igneous source or may have been leached from the country rock. Introduction of all the aluminum from either source by hydrothermal solutions seems most improbable, however, because of the extreme scarcity of kyanite in the numerous quartz veins and its absence in the many pegmatites. Also, it seems very unlikely that in such a large region aluminum would have been introduced only into the sandstone beds and immediately adjacent shale beds. The presence of topaz in the kyanite quartzite might be regarded as indicative of hydrothermal action, and hence pointing to hydrothermal introduction of aluminum. However, the amount of topaz is so small (it was observed in only 8 out of 47 thin sections of kyanite quartzite, and then in amounts that exceeded 1 percent in only a few of these sections) and its distribution so erratic, that its presence cannot be considered as having genetic significance. The topaz may be of detrital origin or may have formed during metamorphism through introduction of small amounts of fluorine into alumina-rich rocks.

Taber (1913, p. 27) also concluded that the kyanite-bearing rocks had been formed by the regional metamorphism of aluminous sedimentary rocks, but he thought that "contact action" of granitic intrusions may have had a part in the metamorphism. His geologic map (1913, pl. 1) shows a large area of granitic rocks whose western border lies about 7 miles east of Willis Mountain. We conclude, however, that the origin of the kyanite quartzite cannot be closely related to the influence of granitic intrusions. The only intrusive rocks of this nature in the vicinity of the kyanite quartzite deposits are the pegmatites and a few small bodies of biotite-quartz syenite and aplite; there is no relation between the distribution of these igneous bodies and the kyanite quartzite.

The weight of the evidence, therefore, is strongly in favor of origin of the kyanite-bearing rocks by the regional metamorphism of alumina-rich sedimentary rocks. Some mobilization of the sedimentary aluminum did take place during metamorphism, possibly through hydrothermal action, but it was probably limited to transfer of aluminum over short distances to form aggregates of massive kyanite in the kyanite quartzite and small amounts of kyanite in some quartz veins in kyanite quartzite.

OTHER MINERAL DEPOSITS

Other mineral deposits within the mapped area include ferruginous quartzite, pegmatite, and a small pyrrhotite-bearing deposit that has been prospected for copper. Gold deposits were mined at one time in a belt extending north from the north end of the kyanite district; slate has been quarried in this same belt at Arvonia for more than 100 years.

IRON

Many of the ferruginous quartzite bodies have been prospected by trenches and shallow pits. The Ayre tract, about 3½ miles east of Dillwyn and just south of Virginia Highway 650 near its junction with Virginia Highway 668, is a typical deposit (pl. 2). Variable amounts of magnetite and specular hematite occur here in layers of fine-grained quartzite having maximum widths of about 20 feet; massive manganiferous garnet partly altered to wad is present in places. One of the shafts here was between 40 and 50 feet deep, according to Taber (1913, p. 20). The other principal prospects in iron and manganese-bearing quartzite in the region are along Virginia Highway 628 about half a mile south of Buffalo Creek, along U.S. Highway 60 about 0.4 of a mile east of the junction with Virginia Highway 632, in a curved belt that extends for a distance of about 2 miles east from a point on Virginia Highway 633 about 0.7 of a mile northwest of Willis River, and north of Virginia Highway 635 about 3 miles west of Curdsville. Taber (1913, p. 19–22) describes several prospects to the north of the mapped area. Prospecting of the iron deposits was probably done when gold mining was most active in the region, about 1829 to 1861. It is doubtful that any of the ore was shipped to iron furnaces; apparently there were no furnaces in the vicinity. Iron was smelted at several furnaces during the middle of the past century near James River, about 30 miles to the west (Espenshade, 1954).

PEGMATITE

The numerous pegmatite bodies in the region are small and have attracted very little prospecting. A pegmatite in kyanite-garnet gneiss on the saddle between Willis and Round Mountains was prospected many years ago by a shaft, 40 to 50 feet deep. Quartz-feldspar-muscovite pegmatite is exposed in the lower half of the shaft; most of the mica books are less than 1 inch in size, though some are as large as 6 inches. Pegmatite and rock containing considerable amphibole, pale-pink garnet, and a little pyrrhotite are found on the dump of this prospect. Pegmatite prospects outside the mapped area in Buckingham, Prince Edward, and Charlotte Counties are described by Jahns and Griffitts (Griffitts and others, 1953, p. 182–183).

COPPER

A copper prospect at the south end of Round Mountain has been described by Taber (1913, p. 28, 113–114). Two shafts were sunk here about 1870; they are caved now, and the material on the dumps gives the only indication of the character of the deposit. Pyrite and pyrrhotite occur with abundant amphibole, garnet, plagioclase (An_{30}), and pale chlorite; a little scapolite is also present.

GOLD

The gold mines and prospects in this region are outside the mapped area in northern Buckingham County, and north of James River in Goochland and Fluvanna Counties. They have been fully described by Taber (1913). The Morrow, or Booker, gold mine lies a few miles west of Willis Mountain (pl. 2). Gold mining was most active from about 1829 to 1861. During this period, gold was mined from placer deposits and from the oxidized upper parts of the veins. The gold in the oxidized ores was mainly in the native state, and was recovered readily from the crushed ores by amalgamation methods. The primary ores below the water table were found to contain considerable sulfide minerals which had only a small proportion of the gold in the native state; the remainder of the gold contained in the sulfides was not recoverable by amalgamation. In the 1890's, sulfide ores were treated by the cyanide and chlorination processes at several of the mines. There seems to have been very little mining during the present century. In 1953 and 1955, the London, Virginia, and Buckingham tracts near Dillwyn were explored for copper, lead, and zinc by means of diamond drilling by the Virginia Mining Co., subsidiary of Belville Gold Mines, Ltd., under contracts with the Defense Minerals Exploration Administration. Sulfide deposits containing considerable pyrite and some chalcopyrite were prospected for copper at three localities in northern Buckingham County many years ago (Taber, 1913, p. 241–259). Deposits along Bear Garden Creek near New Canton were prospected by diamond drilling in 1951 or 1952. Some prospect drilling under contracts with the Defense Minerals Exploration Administration was done in the New Canton area in 1955 by the Virginia Mining Co. and in 1956 by Roland F. Beers, Inc. The old Bondurant gold mine (Taber, 1913, p. 192–195) near Andersonville, a few miles west of Arcanum, was drilled by the New Jersey Zinc Co. in 1957 under contract with the Defense Minerals Exploration Administration.

SLATE

High-quality black roofing slate has been quarried in northern Buckingham County near Arvonia, 12 miles northeast of Dillwyn, for more than 100 years. Slate mining operations and the character of the slate were described by Dale (1914, p. 146–156). Coal beds in Triassic sedimentary rocks just east of the mapped area have been explored at two points north of Farmville, according to Roberts (1928, p. 95).

HALIFAX COUNTY

Kyanite quartzite occurs at several places along a ridge extending southwest from Sandy Creek near Meadville, about 8 miles west-northwest of the town of Halifax, Halifax County, Va. (fig. 35). These deposits have not previously been described; they were brought to our attention by Jesse W. Whitlow, of the U.S. Geological Survey, a former resident of this region.

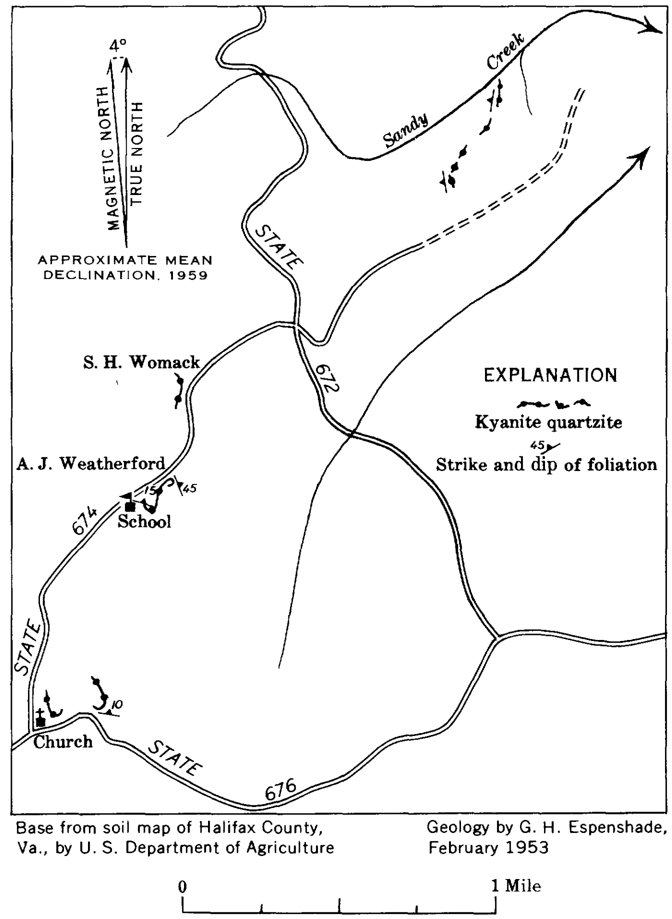


FIGURE 35.—Map of kyanite quartzite southwest of Meadville, Halifax County, Va.

The kyanite quartzite is a light-gray gneissic rock containing pale-green to blue kyanite crystals, about 1/4 to 1/2 inch long and generally in strong linear orientation; muscovite is commonly present also. A few large boulders of nearly massive light-blue kyanite are found on the S. H. Womack property, and some of the rock here also contains large flakes of muscovite. Irregular veins and pods of quartz, 1 to 2 feet thick, cut the kyanite quartzite.

Ledges of kyanite quartzite a few feet high are exposed intermittently for lengths of 50 to 600 feet within a distance of about 2½ miles southwest along the ridge from Sandy Creek (fig. 35). The country northeast of Sandy Creek was not examined; Whitlow (oral communication, 1952) states that he has found kyanite in the alluvium of streams draining into Sandy Creek several miles southwest of the most southerly deposits shown on figure 35.

The quartzite seems to be a bedded deposit. In most outcrops its thickness is between 5 and 10 feet and its maximum true thickness about 10 feet.

The true thickness is readily apparent where the beds dip steeply, but in places where the beds dip gently in the same direction as the hill slope (as in the northernmost group of outcrops), nearly flat ledges and tilted blocks of kyanite quartzite are found across widths of 50 to 150 feet, giving the impression that the beds are much thicker here than they actually are. The general trend of the group of exposures is toward the northeast, but locally the strikes are very irregular. Tight recumbent folds with horizontal axes are evident in some outcrops. The cleavage in some places is tightly crumpled and sliced by slip cleavage, and the kyanite crystals are bent and twisted. The kyanite quartzite appears to have been a thin sedimentary unit that has been strongly deformed and metamorphosed. The intermittent exposures along the ridge may be the erosion remnants of a once continuous bed or may represent originally discontinuous lenses.

The kyanite quartzite is very similar in appearance to the kyanite quartzite in the vicinity of Madisonville and Baker Mountain, about 30 miles to the northeast, but the deposits here are smaller and thinner. Medium-grained biotite granite gneiss containing a few small garnets is exposed just southeast of the intersection of Virginia Highways 672 and 674 and at the crossing of Virginia Highway 672 over Sandy Creek. Exposures and float of hornblende gneiss are found at a few places along the ridge near the kyanite quartzite.

OTHER LOCALITIES

Kyanite is probably widely distributed in small amounts in the metamorphic rocks, pegmatites, and quartz veins of the Piedmont and Blue Ridge provinces in Virginia; the known localities that are not previously described in this report are noted below. Kyanite and andalusite occur together in vein quartz near Difficult Run, 1.6 miles north-northwest of Oakton, Fairfax County, according to Charles Milton (written communication, 1953), of the Geological Survey. Kyanite is found about 2 miles north of Chancellorsville in Spotsylvania County, according to Dana (1892, p. 50). Taber (1913) mentions its occurrence with sillimanite in garnetiferous quartzite near Lantana, Goochland County, and in gneiss and vein quartz at the Young American gold mine, about 1½ miles north of Lantana. Kyanite-rich layers occur in the schist and gneiss of the Anna River pegmatite area in Spotsylvania, Caroline, Hanover, and Louisa Counties, in the Axton pegmatite area in Henry and Pittsylvania Counties, and in the Philpott-Martinsville pegmatite area in Henry County (Griffitts, and others, 1953). Large bladed crystals of blue kyanite occur in pegmatite bodies in Grayson County near Galax (Jonas, 1932). Kyanite occurs with quartz on the farm of P. M. Edelstein (oral communication, 1949) near Evington, Campbell County, and with corundum and andalusite on a knob of Bull Mountain near Stuart, Patrick County (Genth, 1890); we were unable to find this last occurrence.

NORTH CAROLINA

HAGERS MOUNTAIN, PERSON COUNTY

Kyanite-quartz rock is exposed in rugged ledges on Hagers Mountain in Person County, N.C., about 5 miles north of the center of Roxboro and to the west of U.S. Highway 501. The mountain is a low northeast-trending ridge that rises about 150 feet above the surrounding country; it is about three-fourths of a mile long and is cut off at both ends by northwest-flowing streams (pl. 5).

The kyanite-quartz rock crops out as ledges and rugged crags that are several hundred feet long, a hundred feet or more wide, and as much as 40 feet high. The larger outcrops extend for about 2,500 feet along the crest of the ridge; smaller outcrops continue intermittently for about 1,000 feet farther northeast (pl. 5). The rock has very rough, irregular knobby surfaces, and in places resembles a breccia. A rude foliation or schistosity strikes about N. 45° E. and dips steeply east to vertical. Two systems of joints strike north to northwest; one system dips gently east and the other steeply east.

The kyanite-quartz rock is white to light tan or gray on both the weathered and fresh surfaces. It is made up of fine-grained quartz and variable amounts of kyanite, chloritoid, and fine white to tan mica; rutile, ilmenite(?), chlorite, and zircon are minor accessory minerals. Quartz, kyanite, chloritoid, and fine-grained mica are present together in places, but in some varieties quartz is accompanied by only one of these minerals.

Under the microscope, two varieties of quartz are recognizable. One consists of very small unstrained angular quartz grains that range from about 0.05 to 0.5 mm across and average about 0.1 mm; the other variety consists of larger grains, mostly over 0.5 mm, of strained quartz having very intricate sutured grain borders. The coarse quartz was probably formed by recrystallization of the fine-grained quartz; it seems best developed where large kyanite crystals or considerable fine-grained mica is present.

Kyanite crystals are white to light gray and generally less than 5 mm long. In fine-grained quartz, kyanite crystals are commonly very irregular in shape and contain an abundance of included quartz grains. Kyanite in the coarser quartz is generally in large well-formed bladed crystals with few quartz inclusions. Kyanite is hard to recognize in the weathered rock, and it is difficult to estimate visually the amount of kyanite present. Some of the rock contains 20 to 30 percent kyanite, but much of it contains less.

Tiny dark green chloritoid crystals, averaging about 0.2 mm and containing numerous quartz inclusions, are present in much of the rock. Chloritoid generally makes up no more than 10 percent of the rock, but it is the most abundant mineral in boulders of quartz-chloritoid rock that occur as float near the center of the deposit (pl. 5).

In fresh rock exposed by blasting at the southwest end of the ridge (fig. 36) fine-grained intergrowths of kyanite and quartz form an irregular network that cuts and replaces light-gray quartz rock containing chloritoid and a little kyanite; these relations are not apparent on the weathered surface.

Very fine grained mica, tan in color and having a waxy appearance, is present in small amounts in most of the deposit. This mineral was first thought to be pyrophyllite until it was discovered that it gave a strong alkaline reaction with the abrasion pH test (Stevens and Carron, 1948). Subsequent chemical and X-ray analyses have shown that the mineral is mica, and that both the potassium mica (muscovite) and the sodium mica (paragonite) are present (tables 4, 5); the two varieties cannot be distinguished microscopically. This fine mica partly replaces kyanite (fig. 9) and also quartz and chloritoid.

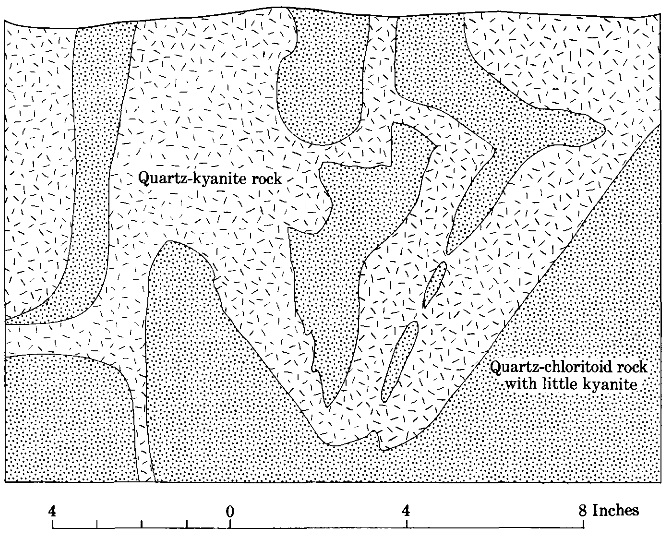


FIGURE 36.—Light-gray quartz-chloritoid rock with a little kyanite veined and replaced by light-tan quartz-kyanite rock, Hagers Mountain, Person County, N.C.

Numerous quartz veins that range in thickness from a few inches to several feet cut the rock; these veins have a northwesterly trend and dip gently northeast. Most of the quartz veins are barren of other minerals, but one vein carries a thin layer of very small prismatic kyanite crystals which are uniformly oriented at right angles to the walls; this was first noted by Stuckey (1935). A little tourmaline is present in one vein.

Fine-grained bluish to greenish-gray siliceous slates and phyllites are exposed along Marlowe Creek at the southwest end of the ridge and along Fishing Branch at the northeast end. Some of the rock contains numerous small feldspar crystals, and some resembles a schistose volcanic breccia; chloritoid is widespread. Under the microscope, the rock is seen to consist of small shreds of biotite and chlorite, abundant epidote grains, and phenocrysts of orthoclase in an exceedingly fine grained (less than 0.01 to 0.02 mm) groundmass of quartz and possibly albite. These rocks appear similar to the siliceous varieties of volcanic porphyries and tuffs mapped by Laney (1917) along the west edge of the Virgilina district, about 2 miles east of Hagers Mountain.

The relations of the kyanite-quartz rock to the surrounding schistose rocks are not clear. The kyanite-quartz rock may represent an originally quartzose sediment occurring as lenticular, folded, or brecciated beds, or it may have been formed by hydrothermal alteration of the volcanic rocks. The latter mode of origin is suggested by the fine-grained character of some of the quartz, which resembles the fine-grained quartz of hydrothermal origin that occurs in the pyrophyllite deposits, such as the one at Bowlings Mountain, Granville County, N.C., 20 miles to the southeast.

CORBETT DEPOSIT, JOHNSTON COUNTY

Kyanite-quartz rock is conspicuously exposed in an area about 400 feet long and 200 feet wide on the Albert A. Corbett property, along the east side of U.S. Highway 70, about 5 miles northwest of Smithfield, Johnston County, N.C. (fig. 37). The deposit has been described briefly by Stuckey (1932, 1937).

The kyanite-quartz deposit is elongated in a northeasterly direction, which is the general trend of the foliation of most of the schistose rocks observed within a few miles of the deposit (fig. 38),

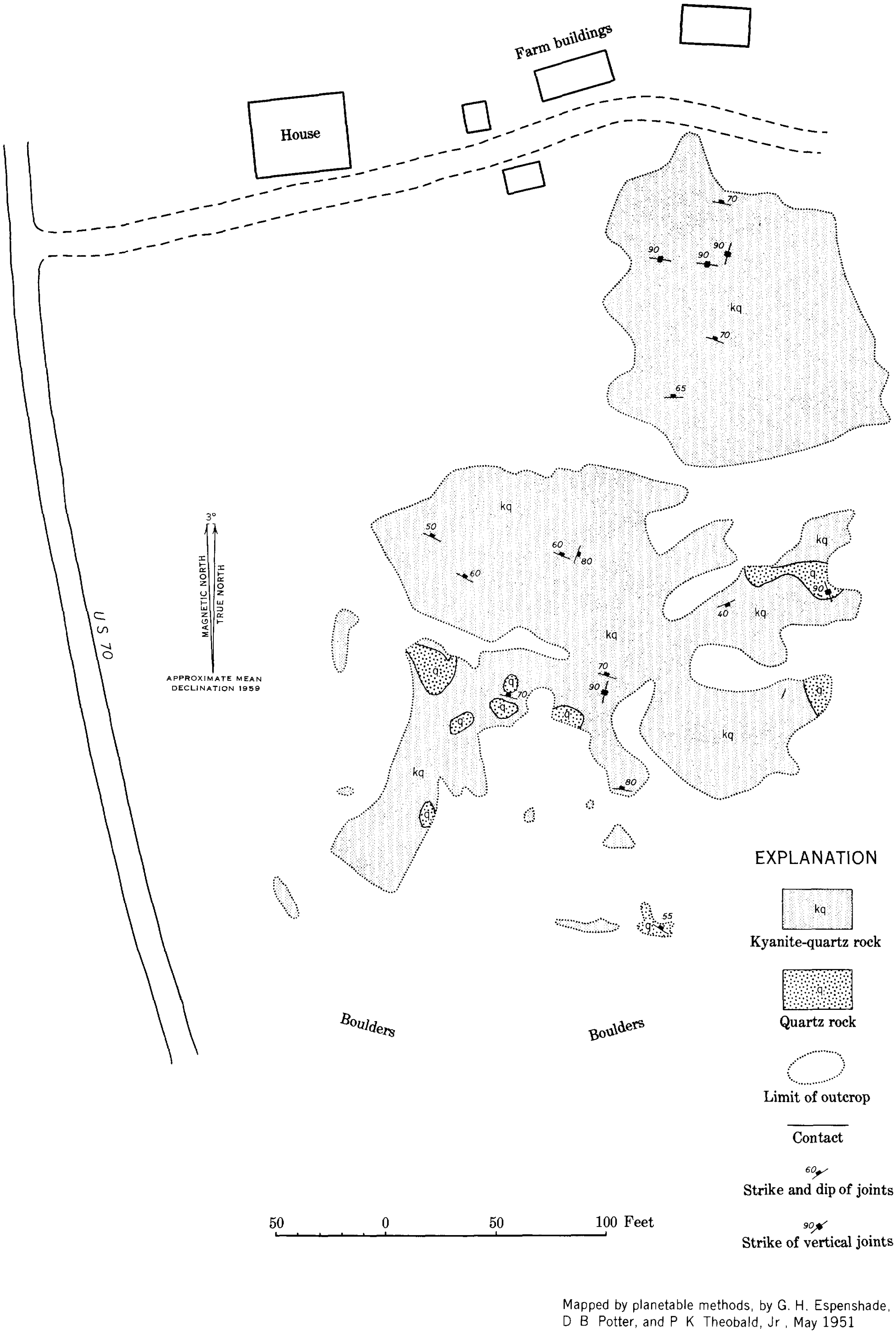
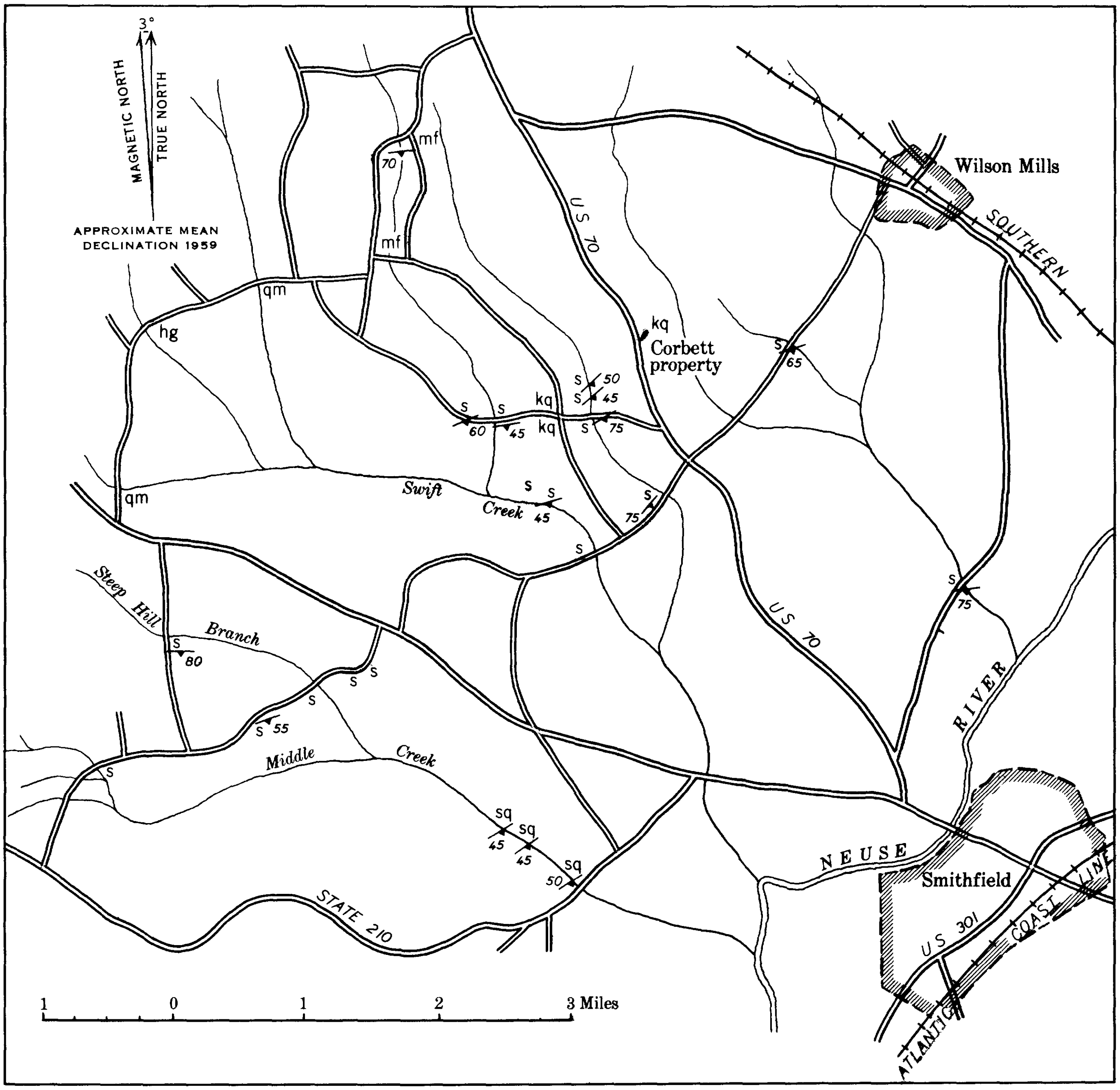


FIGURE 37.—Geologic map of Corbett kyanite deposit, Johnston County, N.C.



Base from North Carolina State Highway Commission map of Johnston County

Rock outcrops mapped by road traverses, by G. H. Espenshade, D. B. Potter, and P. K Theobald, Jr., May 1951

EXPLANATION

kq
Kyanite-quartz rock

hg
Hornblende gneiss

s
Sericite schist

qm
Quartz-muscovite schist

sq
Sericite quartzite

mf
Mica-feldspar gneiss

70
Strike and dip of foliation

FIGURE 38.—Reconnaissance outcrop map of kyanite area, Johnston County, N.C.

but the kyanite-quartz rock is massive and lacks schistosity. Its most prominent structural feature is a northwest-trending set of joints that in general dip between 60° N. and vertical. A weaker joint set is also present; these joints strike northeast parallel to the elongation of the deposit and dip vertically or nearly so (fig. 37).

The exposed area of kyanite-quartz rock is about 2 acres. This area of outcrops may represent the approximate shape and size of the deposit, or it may be that part of the deposit is buried beneath a thin cover of sand and gravel.

The rock is dense and hard, and is composed of fine-grained sugary light-gray quartz through which white to light-gray kyanite is irregularly distributed as small disseminated crystals, as thin stringers and veinlets, and as nodular aggregates of crystals about ¼ to ½ inch long. Irregular masses of quartz composed of angular blocky fragments of quartz a few inches across and resembling a breccia are moderately abundant. The kyanite-quartz rock is exposed in irregular low blocky ledges and flat, pavementlike areas. Some of the fine-grained quartz rock contains no kyanite and forms a few smooth rounded knobs projecting as much as 10 feet above the surrounding outcrops. Considerable fine-grained pyrophyllite occurs in places, particularly with the kyanite-rich masses. Disseminated pyrite was found in a large block of fresh kyanite-quartz rock, broken by dynamite, in the field about 400 feet east of the north end of the deposit; the outcrops are moderately stained by limonite but no pyrite was seen in them.

Under the microscope, the quartz shows a characteristic texture of irregular elongated grains (0.2 to 0.4 mm) having very intricate sutured contacts and strong undulatory extinction. Kyanite typically shows no crystal outlines and contains an abundance of small rounded quartz inclusions; some kyanite crystals are bent, or fractured and veined by quartz. Topaz is present in some of the rock as small rounded grains (0.01 to 0.2 mm across) that are generally grouped in trains or in irregular clusters (fig. 13). Pyrophyllite occurs in places as very fine grained intergrowths that vein and replace both kyanite and quartz. Individual flakes of a micaceous mineral—either muscovite or pyrophyllite—are scattered through some of the rock. Dark-brown grains of rutile are present in the five thin sections studied, and a little zircon occurs in topaz-rich rock.

Proportions of the different minerals are so variable in the different parts of the exposed area that it is not possible to make a visual estimate of the average kyanite content of the rock. In the 5 thin sections examined under the microscope, the quartz content ranged from about 14 to 90 percent, kyanite from 0 to 77 percent, topaz from 0 to 20 percent, pyrophyllite from 0 to about 9 percent, and rutile from 0.2 to 1.0 percent. The samples with the most kyanite contained the most pyrophyllite but had no topaz. In contrast, the high-quartz rock with little or no kyanite contained the most topaz and the least pyrophyllite.

The paragenetic sequence of the principal minerals is quartz (oldest), followed by kyanite and topaz (both about same age?), and then pyrophyllite (youngest). Veins of kyanite as much as 10 inches thick cut the quartz rock. The irregular masses of small quartz blocks in kyanite-quartz rock suggest that kyanite may have been introduced into a brecciated quartzose rock. Coarsely bladed kyanite occurs around the border of one of the rounded quartz masses. A small amount of vein quartz appears to be younger than the kyanite, because some kyanite crystals are broken and veined by quartz. In 1 thin section (fig. 13), topaz and kyanite form trains of crystals that trend 50° to 70° across elongated quartz crystals; they may occur in minute shear planes. The age relations of pyrophyllite were not evident from field examination, but the linear distribution of pieces of pyrophyllite-bearing float suggest that it may occur in veins. In thin section both quartz and kyanite are seen to be veined and replaced by pyrophyllite.

Exposures of fresh rock are very scarce in the region, and are found mainly along or near the streams where the overlying sand and gravel have been removed by erosion. Kyanite-quartz rock was found at only one other locality, about 1 mile southwest of the Corbett deposit (fig. 38). A few low outcrops and large blocks of heavily limonite stained kyanite-quartz rock occur here. The most common rock seen in the region is fine-grained fissile sericitic slaty rock that is tan to greenish brown where fresh. The rock is tightly folded at a few places, but generally has a uniform foliation or schistosity that strikes northeast and dips southeast. A traverse was made up Middle Creek for a distance of about 1 mile from North Carolina Highway 210. Light-green to gray fine-grained sericitic quartzite is well exposed in ledges along the stream. Its foliation also strikes northeast and dips about 45° SE.; at one place, bedding that dips 15° to 20° steeper than the foliation was seen, indicating that the beds at this point are overturned. Several miles west and northwest of the Corbett deposit are outcrops of quartz-moscovite schist with small muscovite flakes, coarse hornblende gneiss, and weathered micaceous feldspar gneiss (fig. 38).

Layers of sand and gravel more than 10 feet thick are widespread in the vicinity; they may be outliers of the Cretaceous sedimentary rocks of the Coastal Plain that are widespread to the east and south of Smithfield. The sand and gravel are heavily impregnated with limonite in places; many years ago near the stream about half a mile east of the Corbett deposit limonitic gravel was mined on a small scale as iron ore.

BURNSVILLE-SWANNANOA AREA, BUNCOMBE, YANCEY, AND MITCHELL COUNTIES

Kyanite has long been known to be abundant in parts of the North Carolina Blue Ridge area, particularly in Buncombe, Yancey, and Mitchell Counties. In his report on the Mount Mitchell quadrangle, Keith (1905, p. 2) briefly describes the kyanite gneisses and their extent, "in a belt 6 to 8 miles wide, passing along the line of Black and Great Craggy mountains," but he does not differentiate the kyanite-bearing rocks on his geologic map. Stuckey (1932, 1937) discussed the occurrence of kyanite in the schists and gneisses and quartz veins and pegmatites here and called this belt the Burnsville-Swannanoa area after the towns near the northern and southern ends of the belt. The geology and mineral deposits of the Spruce Pine pegmatite district are discussed by Kesler and Olson (1942), Olson (1944), Parker (1952), and Kulp and Brobst (1956). These detailed geologic studies of the Spruce Pine pegmatite district have outlined the northern part of the belt (fig. 39). The length of the entire belt of kyanite gneiss between Bandana (4 miles northeast of Burnsville) and Swannanoa is about 30 miles. Keith (1907) and Stuckey (1932, 1937) also mention kyanite gneisses near Sioux on Cane River about 8 miles northwest of Burnsville.

The following account of the occurrences of kyanite in this area has been provided partly by D. A. Brobst (written communication, July 1953), who has mapped a large part of the northern end of the kyanite belt in the Spruce Pine pegmatite district. Light-gray to blue kyanite blades and needles, as much as several inches long, occur in medium-grained biotite gneiss whose other essential minerals are oligoclase, biotite, muscovite, quartz, and garnet (fig. 20). Kyanite also occurs in small lenticular quartz veins and pegmatites. The gneiss varies considerably in its kyanite content, because of the alternation of kyanite-rich layers a few feet thick with kyanite-poor layers; very few layers contain more than 15 percent kyanite. Micaceous gneisses of this belt are of the type that has been called Carolina gneiss. Thin layers of hornblendic rocks (typical of the Roan gneiss) are interlayered with these rocks; the hornblende gneisses do not carry kyanite.

Kyanite was mined from 1934 to 1944 from layers of kyanite-rich gneiss on the slopes of Celo Mountain, 2 miles southeast of Burnsville, Yancey County. The kyanite-bearing rock was quarried from 3 large opencuts, and a small underground opening connected with 1 of the quarries (pl. 6). This rock was crushed and treated in a mill on the hillside just below the quarries. Kyanite, garnet, and roofing mica were recovered by means of dry tables and electrostatic separators in the initial stages of operation (Mattson, 1936); a flotation plant was installed in 1939. The mine was first worked by Celo Mines, Inc., until its closure in 1941. Operations were resumed later that year by Mas-Celo Mines, Inc., but the mine was closed again in June 1942. The operation was reorganized as the Yancey Cyanite Co. in 1943, which began production in February 1943 on a schedule of 12 tons of kyanite concentrates daily. Operations ceased in January 1944, and the mine has been closed since that date; all equipment has been removed.

The kyanite gneiss is considerably folded and faulted, with the foliation generally parallel to the original bedding (pl. 6). Groups of layers in the kyanite gneiss can be correlated reasonably well in the two easternmost quarries (quarries 2 and 3) between points one hundred to several hundred feet apart; these two quarries appear to be nearly alined along the local strike of the gneiss. However, no correlation can be made of layers in quarries 1 and 2, which are also several hundred feet apart but evidently not on strike with one another. A few beds of feldspathic quartzite, several feet thick, are interlayered with the kyanite gneiss. Lenses of pegmatite that carry kyanite occur locally in the kyanite gneiss.

In the fall of 1943, the Geological Survey made a detailed geological examination of this property and took numerous channel samples in the quarries at the request of the Metals Reserve Co.; the results of this work were described by Chute (1944). The objectives of this work were to outline the limits of better grade ore in the hope that selective mining might then be possible and to estimate the reserves of this ore. The study was undertaken because of the gradually declining grade of the mill feed. In July 1943, the mill feed averaged between 7.0

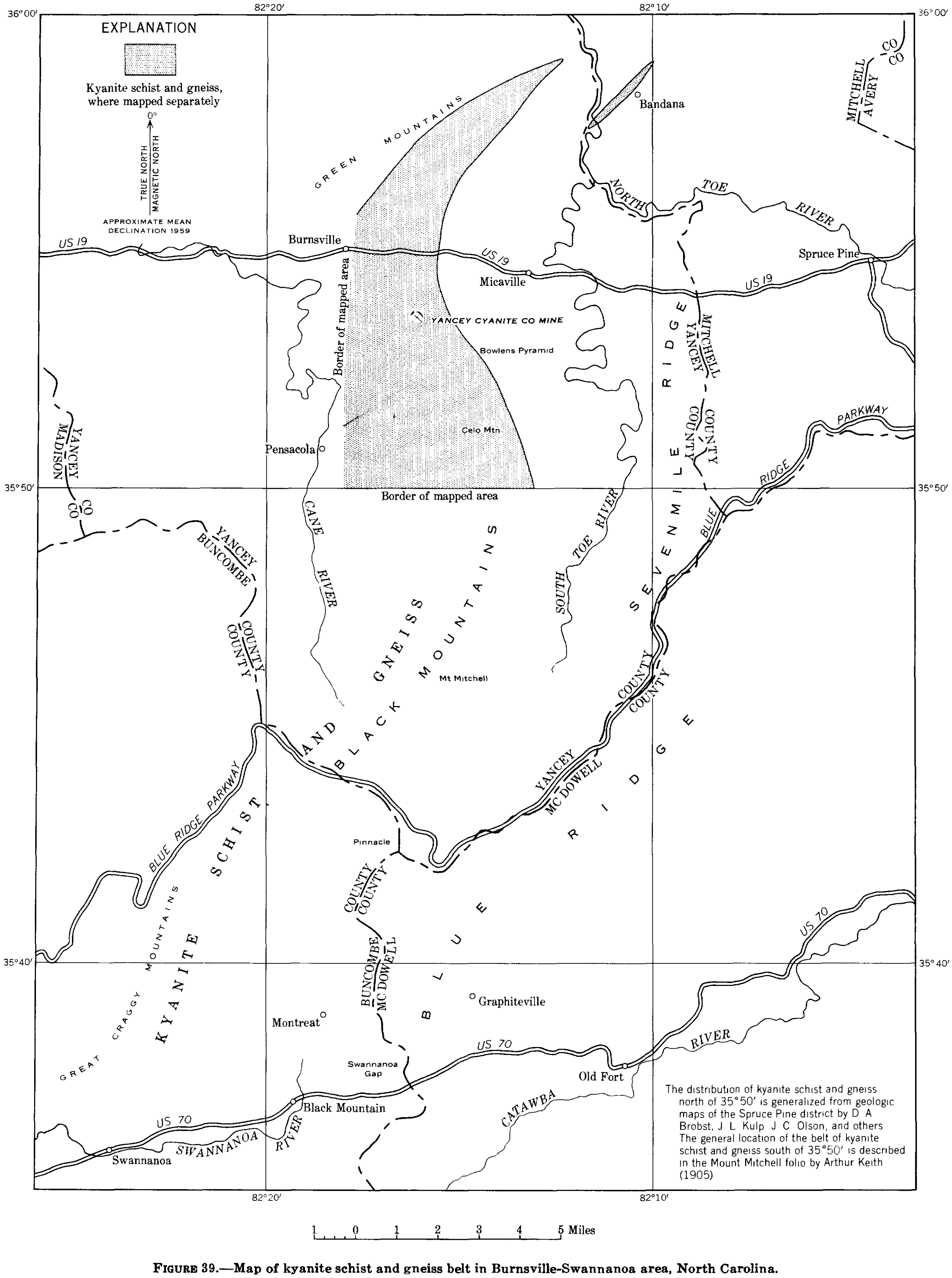


FIGURE 39.—Map of kyanite schist and gneiss belt in Burnsville-Swannanoa area, North Carolina.

and 7.5 percent kyanite in comparison with an average of 10 to 11 percent kyanite in the early years of operation.

The channel samples taken in the quarries by Chute, and from surface exposures by Mattson in 1929, provide excellent information about the distribution of kyanite in the gneiss here. These analyses are indicated on plate 6, and are summarized in table 9, which shows the distribution of samples in groups according to their kyanite content.

TABLE 9.—*Distribution of kyanite in samples of kyanite gneiss from Yancey Cyanite Co. property*

Range in kyanite content (percent)	Percent of samples per grade group	
	Chute's samples [1] (106 total)	Mattson's samples (101 total)
0– 3.9	1.9	13.9
4– 6.9	9.4	21.8
7– 9.9	42.5	17.8
10–12.9	30.2	29.7
13–17.9	16.0	16.8

[1] The amount of kyanite in these samples was determined by heavy-mineral separation methods by R. L. Smith and Roswell Miller III, of the U.S. Geological Survey.

The grade distribution of Chute's samples is not strictly comparable with that of Mattson's samples, because Chute's samples were not of uniform length (they ranged from 1.0 to 6.8 ft long), whereas Mattson's samples were all of the same length (2 ft). Nevertheless, it will be noted that in each group about 16 percent of the samples contain between 13 and 17.9 percent kyanite and about 30 percent contain between 10 and 12.9 percent. However, a much larger pecentage of Chute's samples (42.5 percent) falls into the 7- to 9.9-percent range than do Mattson's samples (17.8 percent). Probably one reason for the difference in this grade range is the fact that Chute's samples were all taken in the quarries, whereas 38 of Mattson's samples were taken from an exposure of lower grade kyanite gneiss to the west of quarry 1.

The amount of garnet in Chute's samples does not range so widely as the kyanite. Garnet content in about 89 percent of the samples ranges from 7 to 12 percent,[6] whereas the kyanite content in about 89 percent of the samples ranges from 7 to 18 percent.

Chute (1944) estimated the reserves of high-grade ore that might be mined by selective methods. Reserves were calculated for zones more than 10 feet thick that carried 12 percent kyanite or better. It was assumed that such ore could be projected 50 feet each way along the strike and 50 feet downdip; no allowance was made for pillars that might be left in underground mining. Five zones of kyanite gneiss that contained 106,474 tons of indicated ore having an average content of 12.5 percent kyanite were outlined. Very little of this ore was mined between the time of Chute's investigation in December 1943 and the shutdown of the mine in January 1944.

Brobst (written communication, July 1953) has estimated that there are about 300 million tons of kyanite gneiss having an average content of 10 percent kyanite to a depth of 50 feet in the northern part of the Burnsville-Swannanoa district. The kyanite content may be less than 10 percent, however, to judge from the record of kyanite mining at Celo Mountain and the samples of kyanite gneiss from there (table 9).

RUTHERFORD COUNTY

Kyanite-quartz rock occurs southeast of Youngs Mountain, Rutherford County, in an area extending about half a mile east from the gravel road skirting the east side of the mountain. The locality lies about 5 miles northeast of the town of Lake Lure, and about 3 miles by gravel road north from U. S. Highways 64–74. The geology of about half a square mile in the vicinity of the deposits was mapped (fig. 40) by P. K. Theobald, Jr., and J. W. Whitlow, of the Geological Survey.

The principal rocks in the vicinity of the kyanite deposits are garnetiferous muscovite schist and biotite-quartz schist which contains few garnets. Biotite granite gneiss occurs here also, but is more widespread to the west where it underlies the main ridge of Youngs Mountain. Fine-grained hornblende gneiss is found in several small bodies in the kyanite area, and occurs in abundance to the north.

Kyanite occurs as very fine grained white fibrous needles in coarse gneissic white quartz rock, accompanied by small shreds of muscovite and tiny rutile grains; the rock has a strong linear structure. The kyanite crystals are so fine grained and needlelike that they resemble sillimanite in the hand specimen, but microscopic examination shows that they are nearly all kyanite with only a very minor amount of sillimanite. The content of kyanite was about 29 percent in 1 thin section examined and 58 percent in another. Coarse blue bladed kyanite is also found in pegmatite lenses. The kyanite-bearing rock occurs mainly as float within the area

[6] Determined by R. L. Smith and Roswell Miller III.

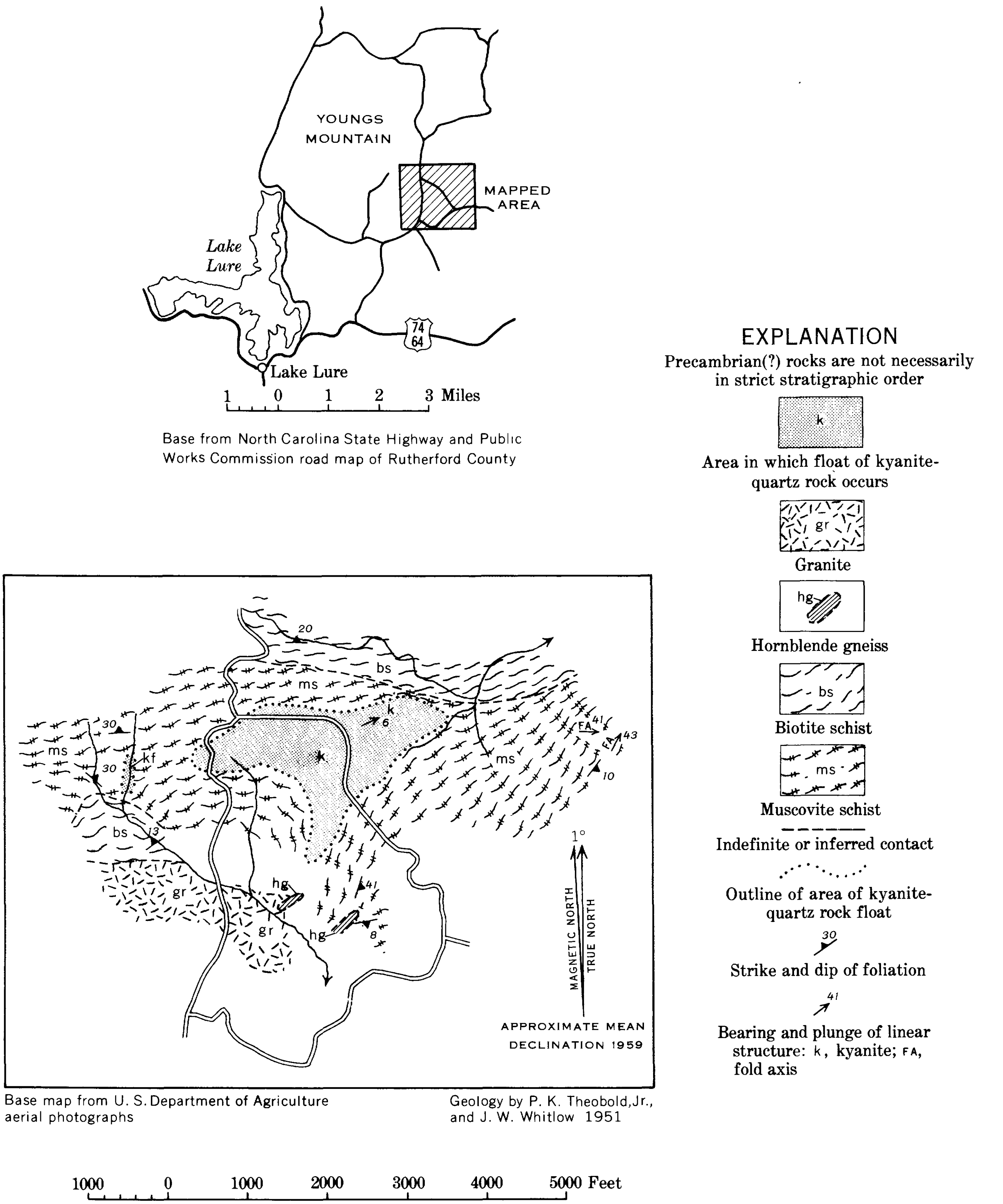


FIGURE 40.—Geologic map of Youngs Mountain kyanite area, Rutherford County, N.C.

shown in figure 40. Elongated blocks of kyanite-quartz rock as much as 10 feet wide and 20 feet long are found at various places within this area. It seems likely that these large blocks were elongated masses of kyanite and quartz in schist that have been set free by weathering and have accumulated on the surface. If this is true, individual bodies of kyanite-quartz rock probably are small and scattered erratically through the schist.

OTHER LOCALITIES

Kyanite is widely distributed in quartz veins and pegmatites in the Blue Ridge area of western North Carolina. In addition to the occurrences in the Burnsville-Swannanoa area and the Warne-Sylva sillimanite district (p. 106), kyanite is found in Cherokee, Haywood, Avery, Wilkes, and Ashe Counties in the Blue Ridge area (Genth, 1891; Stuckey, 1932, 1937). In the western Piedmont, additional kyanite localities are in Surry, Stokes, Iredell, and Mecklenburg Counties, according to Genth (1891). At the locality in northern Iredell County noted by Genth, lenticular aggregates of fibrous bluish-gray kyanite a few inches across are found as scattered fragments of float in an area of garnet-muscovite schist and gneiss, about 1½ miles northeast of Union Grove on the road to Hunting Creek. Additional occurrences of kyanite in the eastern Piedmont are in Wake and Franklin Counties. In Wake County, kyanite-garnet-mica schist crops out at the intersection of North Carolina Highway 264 and the road to Woodland Church, about 3 miles west of Wake Forest. Several shallow prospects for kyanite and mica were dug near here during World War II (Steel, 1952).

NORTH CAROLINA-SOUTH CAROLINA

KINGS MOUNTAIN DISTRICT, CLEVELAND, GASTON, AND LINCOLN COUNTIES, N.C., AND YORK COUNTY, S.C.

The Kings Mountain district is in the center of the Piedmont province at the North Carolina-South Carolina border, about 25 miles west of Charlotte, N. C. Kyanite and sillimanite quartzites occur in two parts of the district, the Crowders Mountain-Henry Knob area at the south and the Reese Mountain–Clubb Mountain area at the north (fig. 41).

The Crowders Mountain-Henry Knob area, covering about 35 square miles, lies in the northeast part of the Kings Mountain quadrangle; the area also includes a very small part of the Clover, Gastonia, and Lincolnton quadrangles to the east, northeast, and north, respectively. The general geology of this area is shown on plate 7. The principal kyanite deposits are at Crowders Mountain, The Pinnacle, the Shelton property, and Henry Knob; the main sillimanite quartzite deposits are at the Will Knox and Ryan-Purcley properties.

The Reese Mountain-Clubb Mountain area (fig. 41) is in the middle of the Gastonia quadrangle, about 15 miles northeast of the Crowders Mountain-Henry Knob area. In the Reese Mountain-Clubb Mountain area only the high-alumina quartzite deposits and the eastern contact of the Yorkville quartz monzonite[7] were mapped (pl. 8). Other metamorphic and igneous rocks were not studied in detail in this area. The principal occurrence of kyanite quartzite in this area is at the north end of Clubb Mountain; sillimanite quartzite is best developed at Reese Mountain and at Machpelah Church.

The geology of the Kings Mountain district was discussed by Keith and Sterrett (1931), and by Kesler (1955). The kyanite deposit at Henry Knob was studied by Newcome,[8] and a discussion of the origin of this deposit is given by Smith and Newcome (1951). Except for sillimanite, records of most of the occurrences of the high-alumina minerals in the district are found in the early literature (Kerr, 1875; Genth and Kerr, 1881; Sloan, 1908). A preliminary account of the present study has been given by Potter (1954). The following special studies also involve this district: Granite (Watson, 1909, 1910), magnetite and brown hematite (Nitze, 1893), manganese (White, 1944), barite (Van Horn and others, 1949), and tin and spodumene (Kesler, 1942).

GENERAL GEOLOGY

The metamorphic rocks of the Crowders Mountain–Henry Knob area are part of a well-defined structural and lithologic belt extending northeast from Gaffney, S.C. This belt is from 5 to 10 miles wide and at least 35 miles long (Keith and Sterrett, 1931; Kesler, 1955; King, 1955; Sterrett, D. B., written communication, 1912). It contains hornblende and mica schists and gneisses, marble, high-alumina quartzite and conglomerate, manganiferous schist, low-grade schists exhibiting relict sedimentary and volcanic textures, and metatonalite, in contrast to the rather monotonous succession of micaceous and hornblendic schists and gneisses to the west. Economic deposits of pegmatite, carrying spodumene and cassiterite, occur in this belt just south of the village of Kings Mountain. In gen-

[7] Originally named the Yorkville granite by Keith and Sterrett (1931), this rock is redefined as the Yorkville quartz monzonite.

[8] Newcome, R. C., 1949, Kyanite at Henry Knob, South Carolina: Master of Science thesis, South Carolina Univ.

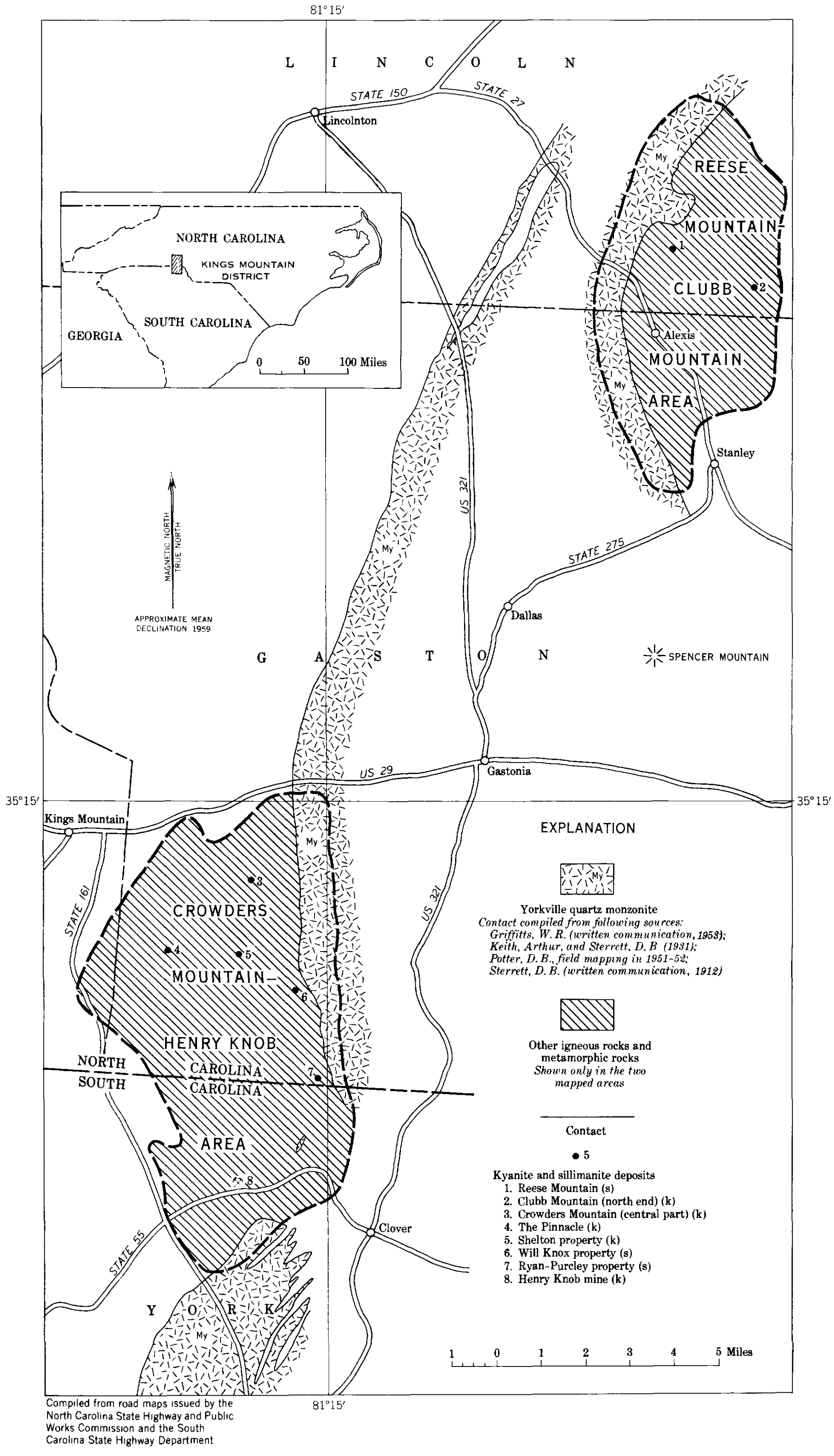


FIGURE 41.—Index map of kyanite and sillimanite deposits in the Kings Mountain district, North Carolina and South Carolina.

eral, tightly compressed northeast-trending isoclinal folds with steeply dipping axial planes distinguish this belt from more open folds to the west. The Yorkville quartz monzonite was emplaced into the rocks along the east side of the belt in Early Mississippian(?) time. The age of the metamorphic rocks is not certain. The lowest rank metamorphism in this part of the Piedmont is recorded in some of these rocks, yet near the Yorkville quartz monzonite the rocks are strongly deformed and highly metamorphosed, indicating that the sedimentary and igneous rocks in the belt were formed before Mississippian time. Some structural and mineralogical evidence (see "Structure" and "Metamorphism") can be interpreted as indicating that these rocks are older than a far-reaching Ordovician orogeny that metamorphosed the rocks to the west (Overstreet and Griffitts, 1955). Diabase dikes of Triassic age cut all the rocks in the belt.

The Crowders Mountain-Henry Knob area is situated about midway north and south, on the east side of this belt, in a zone involving two major converging structures: the northeast-trending belt of metamorphic rocks and the north-trending contact of the Yorkville quartz monzonite (fig. 41; pl. 7). Except for marble, all the metamorphic rock types characteristic of the belt are found in the Crowders Mountain-Henry Knob area.

The metamorphic rocks of the Reese Mountain-Clubb Mountain area, on the east side of the Yorkville quartz monzonite, are probably a continuation of a part of the belt of metamorphic rocks of the Crowders Mountain-Henry Knob area.

Two large plunging folds are suggested by the distribution of beds of manganiferous schist and high-alumina quartzite in the Crowders Mountain-Henry Knob area (fig. 42). These folds are here named the Sherrars Gap syncline, after Sherrars Gap on the east limb of this fold, and the South Fork anticline, after the South Fork of Crowders Creek and its northern tributary, which drain the central part of the area. Primary sedimentary and volcanic textures and structures are evident in some of the rocks in the western part of the area, but, as very few primary features diagnostic of tops and bottoms of beds were found, the anticlinal and synclinal nature of the folds is not well established.

The rocks exhibit a marked increase in grade of metamorphism from the greenschist and albite-epidote amphibolite facies (Turner, 1948) in the western part of the Crowders Mountain-Henry Knob area to the higher subfacies of the amphibolite facies in the eastern part of the area near the Yorkville quartz monzonite (fig. 42). The only pegmatite bodies in the area are within the main body of the Yorkville quartz monzonite and in the metamorphic rocks within about 2,000 feet of the quartz monzonite contact. Pegmatite bodies are somewhat more abundant in the metamorphic rocks of the Reese Mountain-Clubb Mountain area.

The interstream areas in the Kings Mountain district define a gently sloping surface of low relief whose altitude is between 750 and 950 feet. In the Crowders Mountain-Henry Knob area several long hills and ridges rise abruptly 100 to 800 feet above this surface. Some of these hills, such as Crowders Mountain, The Pinnacle, and the north end of Kings Mountain, are prominent regional landmarks. Henry Knob is an isolated hill in the southeastern part of the area. In the Reese Mountain-Clubb Mountain area the hills and ridges are lower, and the maximum relief is 150 feet.

Most of the prominent hills in the district are underlain by kyanite quartzite, fine-grained quartz schist, schistose conglomerate, and sillimanite quartzite. The trend and extent of the kyanite quartzite beds are accurately indicated by the size and shape of the hills. The crests of these hills are usually craggy, precipitous cliffs are common, and the slopes are heavily mantled with talus of kyanite quartzite. The hills underlain by sillimanite quartzite are generally lower and shorter than the ridges underlain by kyanite quartzite.

ROCK TYPES

STRATIGRAPHY

The stratigraphic order of the metamorphic rocks in the district is not well known but is inferred from the somewhat poorly established major folds in the Crowders Mountain-Henry Knob area. The best clues to the stratigraphy and structure are the beds of manganiferous schist, kyanite quartzite, and sillimanite quartzite (fig. 42; pl. 7). Two major folds, the South Fork anticline and the Sherrars Gap syncline, are suggested by the distribution of these marker beds, but the anticlinal and synclinal nature of the folds is not well established because of the paucity of primary sedimentary structures. Questionable crossbedding in quartzite on the northwest side of Lake Montonio, 1 mile southwest of The Pinnacle, and graded bedding in a thick bed of schistose conglomerate on Yellow Ridge indicate the tops of the beds face southeast and that these beds are on the northwest limb of a synclinal fold (the Sherrars Gap syncline). The axial plane of the southwestern half of this fold dips steeply

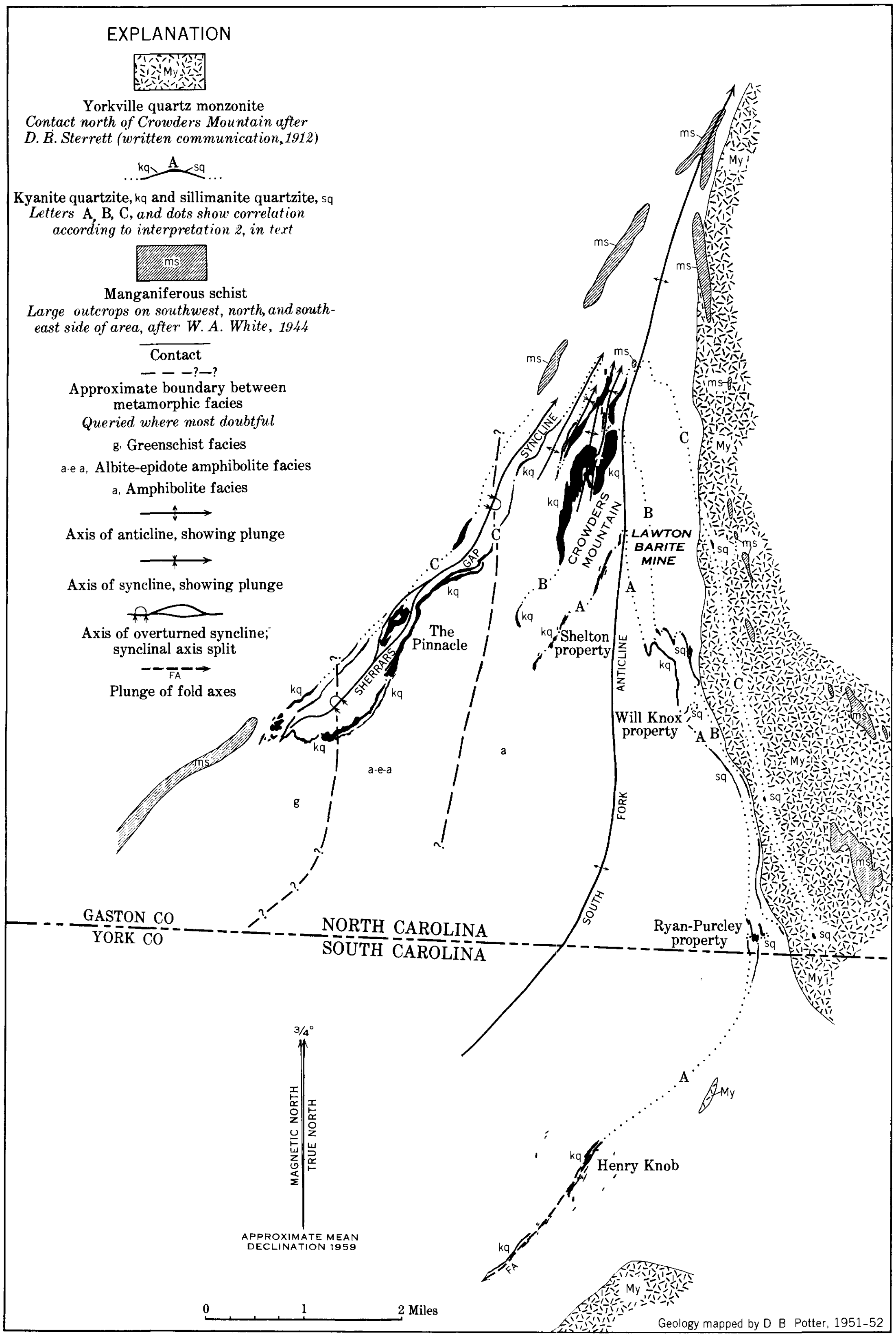


FIGURE 42.—Sketch may of principal structural features, according to interpretation 2, and metamorphic facies in the Crowders Mountain-Henry Knob area, North Carolina and South Carolina.

to the northwest, away from the axis of the much larger South Fork anticline. The Yorkville quartz monzonite has been intruded into the nearly vertical east limb of this anticline.

On the basis of these major folds two principal groups of metamorphic rocks are established: an older group including biotite schist and gneiss, hornblende gneiss, metagabbro, and metatonalite, and a younger group including white mica schist, schistose pyroclastic rock, schistose conglomerate, chloritoid schist, manganiferous schist, and high-alumina quartzite (grading from sillimanite quartzite to kyanite quartzite depending on the rank of metamorphism).

Biotite schist and gneiss, derived from volcanic, sedimentary, and igneous rocks are the most abundant, and probably, in large part, the oldest rocks. They occur at the core of the South Fork anticline, in the vicnity of Gasset Lake, and in two narrow areas along the limbs of the northern end of the Sherrars Gap syncline. Hornblende gneiss, derived largely from volcanic rocks, occurs principally in the core of the South Fork anticline where it is interlayered with biotite schist. Two metamorphosed intrusive rocks occur in the southeastern part of the Crowders Mountain-Henry Knob area; tonalite (metatonalite), metamorphosed in part to biotite gneiss, locally intrudes biotite schist; quartz gabbro (metagabbro), largely metamorphosed to hornblende gneiss, intrudes tonalite. This entire group of older rocks may represent one episode of related sedimentation, volcanism, and intrusion.

The younger group of rocks is exposed in the trough and along the limbs of the Sherrars Gap syncline, in the vicinity of Crowders Mountain, and along the east limb of the South Fork anticline. These younger rocks may be separated from the older group by an unconformity because the marker beds of kyanite and sillimanite quartzites and associated white mica schist on the east limb of the South Fork anticline lie on biotite gneiss, metatonalite, and metagabbro, whereas on the west limb the younger group lies entirely on biotite gneiss.

Plate 7 does not, in many places, present a consistent stratigraphic and structural picture of either group of rocks. Some of the schistose pyroclastic rock in the northwestern part of the area may have been mapped as chloritoid schist because pyroclastic texture, the main distinguishing feature between the two rocks, was obliterated by metamorphism or weathering. White mica schist and some biotite schist along the east limb of the South Fork anticline may represent metamorphosed schistose pyroclastic rock or chloritoid schist. Only the least metamorphosed tonalite was mapped as metatonalite; some white mica schist and much biotite gneiss may represent highly sheared and metamorphosed tonalite. The lenticularity of the quartzite beds makes their correlation difficult. Their lenticularity may be in part an original sedimentary feature but may also be in part the result of flowage and rupture during metamorphism.

Two structural interpretations of the geology of the Crowders Mountain-Henry Knob area are given to explain the distribution of kyanite quartzite, sillimanite quartzite, and manganiferous schist within the framework of the two major folds. According to interpretation 1 there is 1 manganiferous schist bed and 1 high-alumina quartzite bed; interpretation 2 proposes the presence of 1 manganiferous schist bed and 3 beds of high-alumina quartzite.

Interpretation 1.—Under interpretation 1 all the outcrops of high-alumina quartzite and barren quartzite would result from repetition of a single quartzite bed by folding and faulting. In the western part of the area the high-alumina quartzite "bed" actually consists of 2 parallel layers of kyanite quartzite and kyanite conglomerate separated by 20 to 100 feet of schist; at Crowders Mountain the bed is highly folded and thickened, and includes much nonkyanitic quartzite; on the east limb of the South Fork anticline the bed is apparently repeated by an isoclinal syncline, for it occurs as thin parallel lenses of sillimanite and kyanite quartzites.

The suggestion by Keith and Sterrett (1931) that the manganiferous schist is older than the kyanite quartzite is followed here, because the age relationships of these units could not be determined within the area shown on plate 7. Manganiferous schist seems to lie below kyanite quartzite at the southwest end of the Sherrars Gap syncline (fig. 42). However, the distribution of manganiferous schist around the high-alumina quartzite of the South Fork anticline suggests that manganiferous schist is the younger unit. Except for a small lens of manganiferous schist at the north end of Crowders Mountain, this rock is absent from the highly folded areas proposed by interpretation 1. This absence may reflect nondeposition, the shearing out of manganiferous schist along the limbs of very tight and complex folds, or the manganiferous schist may be present in thin lenses but covered by kyanite quartzite talus.

Schistose pyroclastic rock and chloritoid schist occur at two stratigraphic positions, according to both interpretations: an upper sequence in the trough of the Sherrars Gap syncline and a lower sequence beneath kyanite quartzite on both limbs of the syncline. A narrow body of biotite schist occurs in the chloritoid schist of the lower sequence near the northern part of the mapped area (pl. 7). Outcrops of schistose pyroclastic rock west of Yellow Ridge—west of the area shown on plate 7—correspond in stratigraphic position to schistose pyroclastic rock of the lower sequence that crops out just west of Sparrow Springs Lake. The bed of schistose conglomerate, one-half mile east of Oak View Baptist Church, is correlated with the schistose conglomerate bed just west of Yellow Ridge and Lake Montonio.

The abrupt northern termination of the lower schistose pyroclastic beds, three-quarters of a mile north of Sparrow Springs Lake, is, according to this interpretation, produced by faulting. Interpretation 1 also points up the presence of either an unconformity beneath the high-alumina quartzite bed (pl. 7, section *B–B′*) or structural thinning and faulting out of schists that underlie the sillimanite quartzite bed on the east limb of the South Fork anticline. Such a fault is not shown on plate 7.

Interpretation 2.—The broad spatial distribution of the high-alumina quartzite beds alone suggests three separate stratigraphic units distinguished by letters *A*, *B*, and *C* on figure 42. Bed *A*, the oldest, occurs as kyanite quartzite at the Shelton property, southwest of the Lawton barite mine, northwest of the Will Knox property, and at Henry Knob; and as sillimanite quartzite at the Will Knox and Ryan-Purcley properties. Bed *B* makes up the great mass of quartzite in the central and southern part of Crowders Mountain; on the east limb of the South Fork anticline, bed *B* is represented by the long narrow lenses of sillimanite quartzite that lie from 300 to 800 feet east of bed *A*. Bed *B* may be stratigraphically equivalent to the schistose conglomerate bed half a mile east of Oak View Baptist Church, and, if so, the schistose pyroclastic rock just east of Crowders Mountain corresponds to the schistose pyroclastic rock of the lower sequence. Bed *C*, the youngest high-alumina quartzite bed, occurs on both limbs of the Sherrars Gap syncline. Throughout much of this fold the high-alumina quartzite occurs as 2 parallel kyanite quartzite and kyanite conglomerate layers separated by 20 to 100 feet of schist. At Crowders Mountain, bed *C* has been folded along with bed *B*. Some manganiferous schist has been infolded with bed *C* at the north end of Crowders Mountain. On the east limb of the South Fork anticline, bed *C* occurs as a few very small lenses of sillimanite quartzite in the Yorkville quartz monzonite. By comparing plate 7 with figure 42 it will be seen that an unconformity beneath the high-alumina quartzites is not demanded by interpretation 2. On section *B–B′*, plate 7, the position of bed *A* would correspond to the lower contact of the schistose pyroclastic rock on the west limb of the South Fork anticline. Structural thinning could account for the smaller thickness of white mica schist on the east limb of the anticline than on the west.

Regardless of the structural interpretation of the Crowders Mountain-Henry Knob area, deposition of the sediments and emplacement of the igneous rocks which constitute the whole metamorphic sequence occurred before the emplacement of the Yorkville quartz monzonite in Early Mississippian(?) time. Tenuous evidence (see "Structure" and "Metamorphism") suggests that part or all of this metamorphic sequence may be Ordovician or older. The most recent igneous activity occurred during Triassic time when all the metamorphic and igneous rocks in the area were cut by diabase dikes.

The stratigraphic column of all igneous and metamorphic rocks in the Crowders Mountain-Henry Knob area, as deduced from interpretation 1, is given below. The interpretation by Keith and Sterrett (1931) of the stratigraphy of this area is given in a parallel column and correlation between the two columns is indicated by dashed lines.

Two discrepancies of correlation between the two columns are the position of metagabbro and the position of the upper sequence of schistose pyroclastic rock and chloritoid schist. Metagabbro, mapped by Keith and Sterrett as the quartz diorite variety of Roan gneiss, locally intrudes metatonalite (Bessemer granite in part). Chloritoid schist and schistose pyroclastic rock (Battleground schist in part) occur in the trough of the Sherrars Gap syncline as well as stratigraphically below the kyanite quartzite (Kings Mountain quartzite). If the kyanite quartzite is considered to be of Cambrian age, then the upper sequence of chloritoid schist and schistose pyroclastic rock must be Cambrian or younger and not Algonkian, as Keith and Sterrett proposed.

The major rock types in the district are discussed below, beginning with the lithology most characteristic of the oldest stratigraphic unit. Except for the high-alumina quartzites and the Yorkville quartz monzonite the discussion is based entirely on the detailed field and petrographic study

Stratigraphy of Kings Mountain district

Interpretation 1 of present study			Keith and Sterrett (1931)	
Triassic		Diabase dikes	Diabase dikes	Triassic
Early Mississippian(?)		Yorkville quartz monzonite	Yorkville granite	Carboniferous
Early Paleozoic(?) or Late Precambrian(?)	Younger group	Schistose pyroclastic rock, chloritoid schist, minor hornblende gneiss		
		High-alumina quartzite	Kings Mountain quartzite	Cambrian
		Unconformity(?)	Unconformity	
		Manganiferous schist, chloritoid schist, minor biotite schist, schistose conglomerate, schistose pyroclastic rock, white mica schist	Battleground schist	Algonkian
		Unconformity	Unconformity	
	Older group	Metagabbro		
		Metatonalite	Bessemer granite	Archean
		Hornblende gneiss		
		Biotite schist and gneiss	Roan gneiss	

of the rocks in the Crowders Mountain-Henry Knob area.

BIOTITE SCHIST AND GNEISS

Biotite schist and gneiss occur at several places in the stratigraphic column, but are found mainly in the core of the South Fork anticline between Henry Knob and Crowders Mountain, where they are judged to be the oldest rocks. Keith and Sterrett (1931) concluded that much of this biotite schist and gneiss developed through metamorphism of the Bessemer granite. The present study indicates that the only granitic-textured rock in this part of the area is metatonalite; much of the biotite schist and gneiss was derived from volcanic rocks, some from conglomeratic sedimentary rocks, and some from shearing of the metatonalite.

Biotite schist and gneiss in the core of the South Fork anticline and in the vicinity of Gasset Lake are interlayered with hornblende gneiss and with white mica schist. The biotite schist and gneiss are distinctly conglomeratic at several localities. The subangular to subrounded pebbles consist of biotite schist, hornblende gneiss, and quartzite, and range in width from a fraction of an inch to 10 inches. At other outcrops the volcanic origin of some of the biotite gneiss is indicated by the small relict plagioclase phenocrysts. In the vicinity of the area mapped as metatonalite much of the biotite gneiss and schist undoubtedly represents highly sheared tonalite.

Biotite gneiss, interlayered with the lower sequence of chloritoid schist on the limbs of the Sherrars Gap syncline in the northern part of the area, displays relict volcanic texture and contains some hornblende.

Sillimanite-garnet-biotite gneiss and schist occur as long narrow septa in the Yorkville quartz monzonite.

Biotite schist and gneiss are typically fine to medium grained; foliation is well developed. Biotite occurs evenly disseminated or as clusters along foliation planes. Thin sections indicate the principal constituents to be quartz, plagioclase (albite to calcic oligoclase), biotite (partially altered to chlorite in the lower rank rocks), white mica (probably muscovite), and rarely microcline or orthoclase. Sillimanite, garnet, and staurolite occur in schist in the central and eastern part of the area. Many thin sections of schist and gneiss from the central and western part of the area exhibit a relict porphyritic texture and fine-grained groundmass (fig. 43) typical of volcanic rocks. Judging from the mineralogy, the bulk of the metavolcanic biotite gneiss in the area is characterized by a fairly high ratio of soda to potash.

Chemical and spectrochemical analyses of biotite gneiss (sample NG–441) from the vicinity of Trinity Church are given in table 10. This rock consists dominantly of quartz, albite, and biotite; chlorite, muscovite, pyrite, magnetite, epidote, apatite, and tourmaline occur in minor amounts. A few relict plagioclase phenocrysts were seen in thin section. Most of the groundmass consists of very fine grained albite and quartz. This rock occurs in the vicinity of an albitized metavolcanic hornblende gneiss, and it is probable that both rocks were albitized at the time of intrusion of the tonalite, before the metamorphism effected by the intrusion of the Yorkville quartz monzonite.

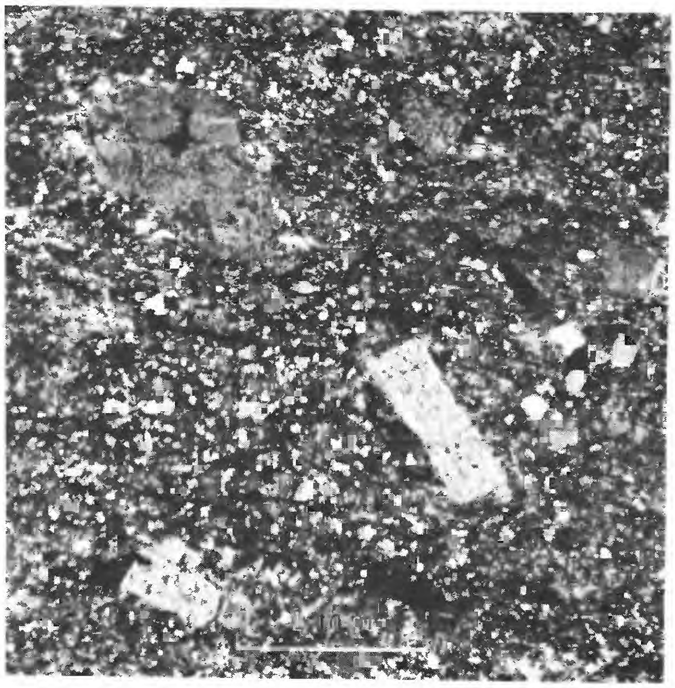


FIGURE 43.—Photomicrograph of metavolcanic biotite gneiss, from creek bed 1,000 feet southeast of Bethany Church, York County, S.C.

TABLE 10.—*Chemical, spectrochemical, and modal analyses of some rocks from the Kings Mountain district, North Carolina–South Carolina*

Chemical analyses

[L. N. Tarrant, analyst]

	NG–441 Biotite gneiss	SY–88 Metatonalite	NG–442 Schistose pyroclastic rock	NG–438 Quartz monzonite	No. 4, South Carolina granites Yorkville quartz monzonite	No. 10, South Carolina granites Yorkville quartz monzonite
SiO_2	70.52	73.89	66.14	71.55	68.90	70.77
Al_2O_3	14.67	14.45	19.44	14.47	15.75	14.89
Fe_2O_3	.68	.56	5.88	.46	1.16	.75
FeO	2.77	1.22	.45	1.51	1.49	1.24
MgO	1.60	.94	.22	.77	.74	.43
CaO	2.29	1.33	.29	2.00	2.66	2.08
Na_2O	4.64	5.56	2.61	3.72	4.76	4.47
K_2O	1.34	1.04	1.62	4.16	3.49	4.70
H_2O-	.03	.04	.09	.02	....	....
H_2O+	.59	.61	2.33	.34	....	....
Ignition	....	....	....	....	.18	.19
TiO_2	.42	.28	.64	.40	.36	.36
CO_2	.02	.01	.01	.23	....	....
MnO	.05	.04	.01	.06	Trace	Trace
P_2O_5	.08	.05	.14	.13	Trace	Trace
S	.38	....	.00	....	....	....
SO_3	....	....	....	....	Trace	Trace
	100.08	....	....	....	....	....
Less O for S	.10	....	....	....	....	....
Total	99.98	100.02	99.87	99.82	99.49	99.88

Spectrochemical analyses

[P. R. Barnett, analyst. Zeros in unit column signify that the elements were not detected; sensitivity limits for these elements are: B, 0.003; La, 0.005; Mo, 0.0001; Ni, 0.0003; Pb, 0.0006. Elements not detected in any of the samples, together with their sensitivity limits, are: Ag, 0.0005; As, 0.05; Au, 0.003; Bi, 0.001; Cd, 0.005; Ge, 0.0005; In, 0.001; Nb, 0.001; Pt, 0.003; Sb, 0.01; Sn, 0.001; Ta, 0.05; Th, 0.05; Tl, 0.01; U, 0.05; W, 0.01; and Zn, 0.01]

B	0.003	0	0.008	0	....	....
Ba	.1	.03	.05	.1	....	....
Be	.0001	.0001	.0002	.0007	....	....
Co	.0007	.0003	.001	.0005	....	....
Cr	.0009	.0003	.0009	.002	....	....
Cu	.0007	.0004	.0007	.0009	....	....
Ga	.001	.001	.001	.002	....	....
La	0	0	.006	.009	....	....
Mo	0	.0001	0	0	....	....
Ni	.0004	0	.0009	.0005	....	....
Pb	.0008	0	.001	.008	....	....
Sc	.0005	.0003	.001	.0002	....	....
Sr	.2	.08	.2	.2	....	....
V	.006	.004	.01	.004	....	....
Y	.005	.003	.01	.002	....	....
Yb	.0004	.0003	.0008	.0001	....	....
Zr	.01	.01	.01	.02	....	....

TABLE 10.—*Chemical, spectrochemical, and modal analyses of some rocks from the Kings Mountain district, North Carolina–South Carolina*—Continued

MODES

Metatonalite

[Average of 8 thin sections from different localities]

	Percent		Percent
Sodic oligoclase and albite	54	Biotite	7
Microcline	1	Muscovite	3
Quartz	35		

Minor: Chlorite, epidote, magnetite, pyrite, apatite, sphene, rutile, zircon, garnet, staurolite, and kyanite.

Yorkville quartz monzonite

[Average of 6 thin sections from different localities]

	Percent		Percent
Calcic oligoclase	31	Quartz	27
Albite and sodic oligoclase	4	Biotite	11
Myrmekite	2	Muscovite	2
Microcline	21		

Minor: Epidote, sphene, apatite, ilmenite, zircon, pyrite, and allanite.

Location of samples:

NG–441, Lab. No. 52–1609CDSW. Composite sample of 6 pieces of biotite gneiss taken over distance of 100 ft across strike of outcrop, 2,200 ft N. 70° W. of Trinity Church, Gaston County, N.C.

SY–88, Lab. No. 52–1612CDSW. Composite sample of coarse-grained metatonalite from streambed 1.85 miles N. 40° E. of crest of Henry Knob, York County, S.C.

NG–442, Lab. No. 1610CDSW. Composite sample of 6 pieces of schistose pyroclastic rock from pipeline excavations 1 mile S. 58° E. of Stepps Gap, Gaston County, N. C.

NG–438, Lab. No. 52–1606CDSW. Composite sample of 6 pieces of coarse-grained porphyritic Yorkville quartz monzonite from small quarry 0.9 mile southwest of Machpelah Church, Lincoln County, N. C.

No. 4 of Watson's South Carolina granites (Watson, 1910, p. 174): Biotite granite, Jackson quarry, 0.5 mile north of Clover, York County.

No. 10 of Watson's South Carolina granites (Watson, 1910, p. 174): Muscovite-bearing biotite granite, Whiteside quarry, 2 miles west of Filbert, York County.

HORNBLENDE GNEISS

The principal occurrence of hornblende gneiss is in the vicinity of Trinity Church, 3.7 miles northeast of Henry Knob (pl. 7). Hornblende gneiss also occurs as layers in biotite gneiss at the core of the South Fork anticline and in the upper sequence of schistose pyroclastic rock in the trough of the Sherrars Gap syncline north of The Pinnacle. Thin septa of hornblende gneiss occur locally in the Yorkville quartz monzonite.

Hornblende gneiss at these localities was apparently derived from volcanic rocks of intermediate to basic composition. The gneiss is fine to medium grained; the relict porphyritic texture is seen in some places. Foliation and lineation are generally well developed. The principal constituents are seen in thin section to be plagioclase (An_{10}–An_{40}), green hornblende, quartz, and biotite. Accessory minerals include epidote, magnetite, sphene, apatite, zircon, and garnet. Relict porphyritic texture, similar to that in figure 43, is commonly seen in thin section.

An elongated area of about half a square mile just south of Trinity Church is underlain by a massive medium-grained light greenish-gray rock containing numerous epidote veins. In thin section this rock is seen to consist dominantly of a fine-grained aggregate of albite and quartz, a few percent of hornblende or tremolite, and minor amounts of epidote, pyrite, sphene, apatite, chlorite, and garnet. Some of the original phenocrysts are still present in the rock in the form of partially replaced and bent coarse albite crystals and partially chloritized pigeonite. Albitization of this rock may have taken place in the late stages of the igneous episode which included the eruption of volcanic rocks and intrusion of tonalite.

The hornblende gneiss occurring as septa in the Yorkville quartz monzonite appears to be more highly recrystallized than hornblende gneiss elsewhere in the area. This rock commonly has a porphyroblastic texture produced by dark coarse-grained hornblende crystals.

METATONALITE

Coarse-grained light-gray oligoclase tonalite[9] (trondhjemite) crops out as two elongated bodies north and west of Henry Knob (pl. 7). In the Crowders Mountain-Henry Knob area this is the only granitic-appearing rock occurring in the belt mapped as Bessemer granite by Keith and Sterrett (1931). Much of this rock has been metamorphosed to biotite gneiss, and the coarser grained variety of this gneiss has been mapped with the granitic-textured rock as metatonalite (pl. 7).

Primary igneous textures and structures are seen in the rock at several places. Angular inclusions of biotite schist ranging from 1 inch to more than 10 feet in maximum dimension are common in the tonalite. Locally, tonalite has been injected into a brecciated zone of biotite schist. These features, in addition to the phenocrystic nature of the quartz, suggest a magmatic origin for the rock; it may have been a relatively shallow intrusive body genetically related to the volcanic episode which gave rise to the rocks that are now biotite schist and gneiss and hornblende gneiss.

The least metamorphosed tonalite has a massive appearance. Biotite is evenly distributed through the plagioclase-quartz groundmass; quartz phenocrysts occur as ellipsoidal or spherical "eyes," and rarely as euhedra. In the more highly metamorphosed tonalite, biotite occurs as clusters along well-developed foliation planes, and quartz phenocrysts are flattened and elongated. Flattened quartz "eyes" occur in some white mica schist that apparently developed through shearing and metamorphism of tonalite.

[9] The rock is a tonalite or quartz diorite (228) according to Johannsen (1932).

The highly sodic character of the tonalite is indicated by the mode and chemical analysis, table 10. Thin-section study shows that coarse-grained plagioclase crystals are generally embayed and partially replaced by albite and quartz. Quartz phenocrysts are commonly partially recrystallized to a fine-grained aggregate of quartz, though some show perfect hexagonal outlines. Albitization and silicification, as well as local replacement of plagioclase by epidote, are thought to be late magmatic alterations. It is likely that the local albitization of some volcanic rocks (now hornblende gneiss and biotite gneiss) was related to this late magmatic alteration. Metamorphism of the tonalite brought about the recrystallization of quartz phenocrysts, the development of foliation, and, locally, the metamorphic minerals staurolite, garnet, and kyanite.

METAGABBRO

Metagabbro is the name assigned to the metamorphosed quartz gabbro occurring in the southeastern part of the area. This rock ranges from a massive coarse-grained quartz-hornblende gabbro to fine- to medium-grained strongly foliated hornblende gneiss.

The principal areas of exposure are a triangular area one-half mile northeast of Henry Knob and a large area southeast of Henry Knob (pl. 7). Some biotite gneiss occurs with metagabbro in the latter area. Dikes of quartz gabbro, ranging from a few inches to 100 feet in thickness, cut the metatonalite northeast of Henry Knob.

The principal constituents of the metagabbro are labradorite (An_{50-70}), green hornblende, and quartz. Accessory minerals include biotite, epidote, and magnetite. In the least metamorphosed quartz gabbro, labradorite crystals are seen to be only slightly bent and the albite twin planes are sharp. In the more highly metamorphosed quartz gabbro, labradorite crystals contain abundant small quartz inclusions and albite twin planes are invariably irregular and fuzzy.

WHITE MICA SCHIST

Fine- to medium-grained quartz-white mica schist having well-developed foliation is the second most abundant rock type in the area. This schist is commonly pyritic; near the beds of kyanite and sillimanite quartzites it commonly contains minor amounts of high-alumina minerals.

Some of this schist is sedimentary in origin, some volcanic, and some has developed through the shearing and hydrothermal alteration of tonalite and other rocks. Inasmuch as the white mica schist is mapped as one unit, its areal distribution does not give a consistent structural pattern (pl. 7).

One large belt of white mica schist, associated in part with kyanite quartzite, extends northeast through Sparrow Springs Lake and along the east side of Crowders Mountain (pl. 7). This belt is continuous with the belt of white mica schist associated with sillimanite quartzite that extends southeast from Crowders Mountain to the Will Knox property. The latter belt is nearly continuous with the long narrow belt of schist associated with sillimanite quartzite that extends south from a point just southeast of the Will Knox property through the Ryan-Purcley property to the vicinity of Henry Knob. The narrow belts of white mica schist and associated high-alumina quartzite may mark the trough of a tight syncline. Much of the schist in these belts is apparently of sedimentary origin and lies stratigraphically above the thick sequence of biotite schist and gneiss which occupies the core of the South Fork anticline. Scattered remnants of mottled-bluish schistose pyroclastic rock occur at a few places along McGill Branch and at the Ryan-Purcley property; it is probable that some of the white mica schist near these remnants was formed by metamorphism of schistose pyroclastic rock.

Near Sparrow Springs Lake, the schist is interlayered with phyllite; small crystals of tourmaline are present in both phyllite and schist. In the vicinity of the kyanite quartzite beds southeast of Crowders Mountain, the schist carries minor amounts of andalusite, staurolite, and kyanite; at the Shelton property, a little andalusite; and near the sillimanite quartzite beds, minor amounts of sillimanite, andalusite, garnet, rutile, zircon, and tourmaline.

The thick sequence of white mica schist that surrounds the kyanite quartzite in the vicinity of Henry Knob is partly of volcanic origin. Thin sections of some of this schist show relict porphyritic texture. In addition to quartz and white mica this rock carries variable amounts of pyrite, and, in the vicinity of the kyanite quartzite beds, staurolite, andalusite, kyanite, and tourmaline.

Narrow zones of white mica schist, developed by shearing and hydrothermal alteration of the tonalite, occur at numerous places throughout the body of tonalite.

SCHISTOSE PYROCLASTIC ROCK

A distinctive fine-grained mottled-gray schist, containing angular fragments of porphyritic volcanic rock, crops out in various places in the northern part of the area. This schist is locally interlayered with, and genetically related to, chloritoid schist.

The principal occurrences of schistose pyroclastic rock are (a) a large northeast-trending belt southeast of Kings Mountain; the schist in this belt constitutes part of the lower sequence of chloritoid schist and schistose pyroclastic rock, and in 1952 was well exposed in the excavation for the gas pipeline east of Oak View Baptist Church; (b) with chloritoid schist in the trough of the Sherrars Gap syncline, constituting the upper sequence; (c) associated with kyanite quartzite along the east side of Crowders Mountain and at McGill Branch (see "White mica schist"), and with sillimanite quartzite at the Ryan-Purcley property.

The schistose pyroclastic rock is also intimately associated with metavolcanic hornblende gneiss and chlorite schist, both of which exhibit relict porphyritic texture in thin section. Other associated rocks are fine-grained ferruginous quartzite and fine-grained quartz-albite schist, probably a metamorphosed tuff.

The schistose pyroclastic rock is typically a fine-grained well-foliated thin-bedded mottled-gray schist (fig. 44). The mottling is caused by variable amounts of fine-grained disseminated iron ore (hematite or titaniferous hematite) in the fragments and matrix. Where iron ore is particularly abundant in both fragments and matrix, the schist is bluish gray. The angular fragments, consisting for the most part of porphyritic volcanic rock and ferruginous schist, are generally flattened and elongated in the plane of foliation. The schistose conglomerate exposed half a mile east of Oak View Baptist Church (fig. 45) is a conglomeratic facies of the schistose pyroclastic rock.

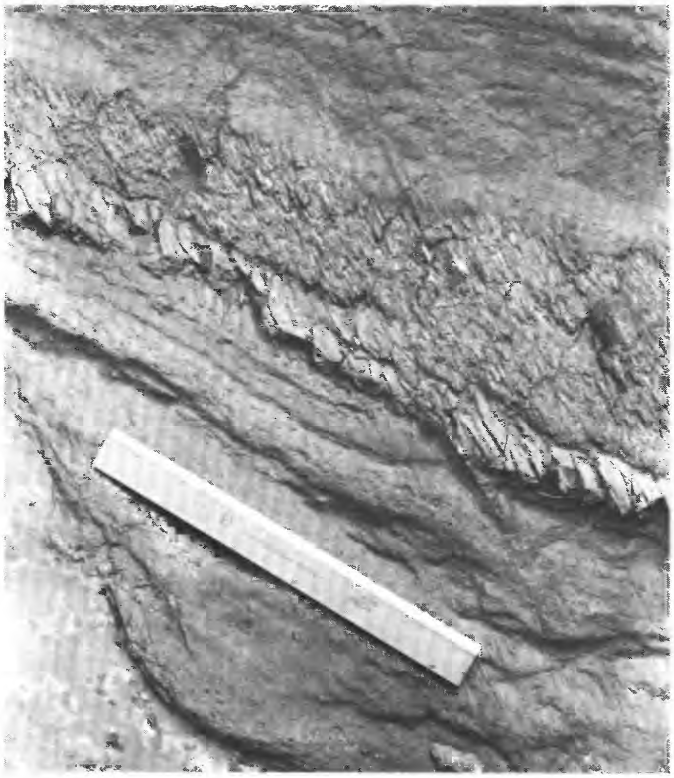


FIGURE 44.—Highly weathered gently dipping thin-bedded schistose pyroclastic rocks half a mile north of Sparrow Springs Lake, Gaston County, N.C. Note fragments in coarse-grained bed that are flattened and elongated in plane of steeply dipping foliation. Scale, 1 foot long. Photograph by W. C. Overstreet.

FIGURE 45.—Schistose conglomerate, 0.45 mile N. 75° E. of Oak View Baptist Church, Gaston County, N.C. Outcrop of flattened and elongated pebbles of fine-grained ferruginous quartzite in groundmass of fine-grained quartz and white mica. Scale, 1 foot long. Photograph by W. C. Overstreet.

Andalusite, kyanite, and sillimanite are locally present in the schistose pyroclastic rock in the vicinity of the high-alumina quartzite beds. Andalusite occurs as coarse crystals, up to half an inch across, in schist just west of the kyanite quartzite bed south of Crowders Mountain village. In thin section (fig. 46) this andalusite is seen to occur as porphyroblasts partially replaced by fine-grained white mica and tourmaline. Kyanite is locally abundant in the schistose pyroclastic rock at the north end of Kings Mountain.

A sample of schistose pyroclastic rock was found to contain 19.44 percent alumina (table 10) and to consist of quartz and white mica in equal amounts, 5 to 10 percent hematite or titaniferous hematite, and minor amounts of tourmaline, apatite, and chloritoid. The white mica is assumed, on the basis of the chemical analysis, to be either a mixture of paragonite and muscovite or a mica of intermediate composition.

The pyroclastic fragments, pebbles, and high-alumina nature of the schistose pyroclastic rock suggest it was originally a mixture of pyroclastic and sedimentary material.

CHLORITOID SCHIST

Chloritoid schist is the dominant rock in the northwestern part of the area. It is locally interbedded with kyanite quartzite, schistose conglomerate, schistose pyroclastic rock, and also with the following rocks which, in the northwestern part of the area, were not mapped as separate units: White mica schist, fine-grained quartzite, and phyllite.

Chloritoid schist occurs at two stratigraphic positions: in a lower sequence including schistose pyroclastic rock and schistose conglomerate on both limbs of the Sherrars Gap syncline (pl. 7) and in an upper sequence including schistose pyroclastic rock in the southwestern part of the trough of the syncline.

Chloritoid schist is typically a fine-grained strongly foliated tan, gray, or bluish-gray porphyroblastic schist. The principal minerals are white mica, quartz, chloritoid (staurolite within the amphibolike facies), and chlorite. The quartz generally occurs as small clastic grains; a few small pebbles of quartzite occur locally in the schist. At several places in the area the schist exhibits thin layers or bands produced by alternating chloritoid-rich and chloritoid-poor layers; these probably reflect compositional layering in the parent sediment.

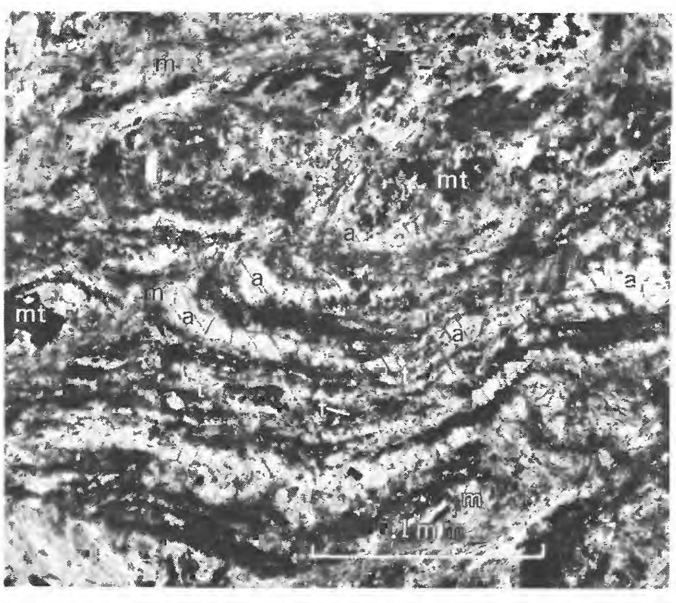


FIGURE 46.—Photomicrograph of partially replaced andalusite porphyroblast in schist, 0.4 mile south of Crowders Mountain village, Gaston County, N.C. Andalusite (a), showing prominent cleavage, at the nose of a small fold, has been partially replaced along foliation planes by white mica (m) and tourmaline (t). Coarse-grained opaque mineral is magnetite (mt). Crossed nicols.

510205 O - 60 - 6

In thin section the chloritoid is seen as small pleochroic blades or radiating aggregates that have formed at various angles to the plane of foliation. Common accessory minerals include magnetite, hematite, tourmaline, rutile, and zircon. Rare accessory minerals include epidote, garnet, and biotite.

Chloritoid schist in both the upper and lower sequences cuts across the boundary between the greenschist and albite-epidote amphibolite facies (cf. pl. 7 and fig. 42) with but little change in mineralogy save an increase in the amount of chloritoid in the higher rank. Chloritoid schist of the lower sequence cuts across the boundary between the albite-epidote amphibolite and amphibolite facies. Although the mineralogy of the schist within the amphibolite facies is not well known, it appears that staurolite occurs in small amounts at the facies boundary and that, in general, staurolite becomes more abundant to the east.

The clastic nature of the small quartz grains, the presence of a few small quartzite pebbles, the aluminous minerals chloritoid and white mica, and the banded structure of the chloritoid schist indicate that the parent rock was a fine-grained clastic sediment, probably a silty clay.

A key marker bed of schistose conglomerate, extending northeast discontinuously for about 3 miles from Lake Montonio, is associated with chloritoid schist on the northwest limb of the Sherrars Gap syncline. This bed consists mainly of coarse pebbles of white quartzite in a phyllitic groundmass. At Yellow Ridge the pebbles in this 60-foot bed exhibit a gradation in size, being finer towards the southeast. This apparent graded bedding suggests that the top of the bed faces southeast. This schistose conglomerate may be the same bed that occurs with schistose pyroclastic rock east of Oak View Baptist Church on the southeast limb of the Sherrars Gap syncline.

MANGANIFEROUS SCHIST

Manganiferous schist occurs at six different localities in the northeastern part of the Crowders Mountain-Henry Knob area (pl. 7; fig. 42). The schist is exposed in the streambed at the north end of Crowders Mountain and in a streambed 0.7 mile east-northeast of Gasset Lake. The other localities were mapped on the basis of float and the characteristic dark-brown to black color of the soil.

In the two exposures of manganiferous schist, one of which is a septum in the Yorkville quartz monzonite, the schist is fine grained and sheared. Manganese oxides occur extensively through the schist as purplish-black and dark-brown coatings on quartz and mica.

Float of spessartite-quartz rock was found in the areas mapped as manganiferous schist within the area of exposure of the Yorkville quartz monzonite. This rock is fine grained, massive and dense, and has a sooty-black coating of manganese oxides. Spessartite constitutes about 60 percent of this rock; other constituents are quartz, hornblende, biotite, and magnetite.

Manganiferous schist appears to occur as highly lenticular beds at a single stratigraphic position, but it is not certain whether manganiferous schist is older or younger than kyanite quartzite. (See "Interpretation 1," p. 68.)

White (1944), and Keith and Sterrett (1931) made more detailed studies of the manganiferous schist in the district.

KYANITE QUARTZITE

Kyanite quartzite occurs as well-defined steeply dipping beds and lenses in both the Crowders Mountain-Henry Knob and Reese Mountain-Clubb Mountain areas. The resistance of kyanite quartzite to weathering makes it one of the most useful mapping units in the metamorphic sequence; the interpretations of structure and stratigraphy are based largely upon the outcrop pattern of kyanite and sillimanite quartzites. Figure 42 shows the distribution of kyanite quartzite in the Crowders Mountain-Henry Knob area. The principal occurrence of kyanite quartzite in the Reese Mountain-Clubb Mountain area is at Clubb Mountain (pl. 8). Small scattered lenses of kyanite quartzite occur north and south of Clubb Mountain.

The kyanite quartzite beds in both areas range from 20 to 35 feet in thickness; their outcrops are commonly much wider because of repetition by small isoclinal folds and flowage of material to the noses of large folds. Most beds can be traced for several hundred feet along their strike, and 1 quartzite and conglomerate bed on the east limb of the Sherrars Gap syncline can be traced almost continuously for 3½ miles. Kyanite quartzite commonly occurs as two or more parallel layers in a thick sequence of schist. In the southern half of the Sherrars Gap syncline, 2 parallel beds are separated by 20 to 100 feet of schist (pl. 7). Beds and lenses of kyanite quartzite arranged in echelon at Henry Knob (fig. 42), at the north end of Clubb Mountain (pl. 9), and at several other localities probably indicate repetition of 1 or 2 layers by steeply plunging isoclinal folds.

Although kyanite quartzite exhibits little variation in composition, texture, and structure within a single deposit, there are some significant variations throughout the district. Kyanite quartzite grades along strike to kyanite conglomerate and also grades into micaceous kyanite quartzite and kyanite schist. Compositional layering is also exhibited locally throughout the district: discontinuous beds, 2 to 5 feet thick, carrying 75 to 90 percent kyanite occur just below the main kyanite quartzite bed at the north end of Kings Mountain; thin layers, very rich in kyanite, occur in quartzite at the north end of Clubb Mountain; kyanite quartzite is interlayered with staurolite quartzite and with kyanite-staurolite-chloritoid quartzite at Crowders Mountain and on the east limb of the Sherrars Gap syncline south of Crowders Mountain village; kyanite quartzite is interlayered with nonkyanitic ferruginous quartzite at Crowders Mountain, at the Shelton property, and half a mile northeast of the Shelton property. Intimate interlayering of kyanite quartzite, micaceous kyanite quartzite, and nonkyanitic quartzite is shown in a small isoclinal fold (fig. 47) from Crowders Mountain.

A pronounced foliation (fig. 48) and tight isoclinal or irregular folding (figs. 47 and 49) are characteristic of most outcrops of kyanite quartzite. These folds have amplitude and wave lengths ranging from 6 inches to 20 feet; their axial planes are vertical or steeply dipping; in many the direction and magnitude of plunge of the axes of these folds have no apparent relation to the major folds (see "Structure").

Kyanite quartzite is typically a coarse-grained medium-gray rock having pronounced foliation. On weathered surfaces the kyanite blades generally project above the less resistant quartz groundmass; the rock is commonly stained with limonite derived from the weathering of pyrite in the quartzite. Kyanite occurs as single blades, tufted aggregates (fig. 5),

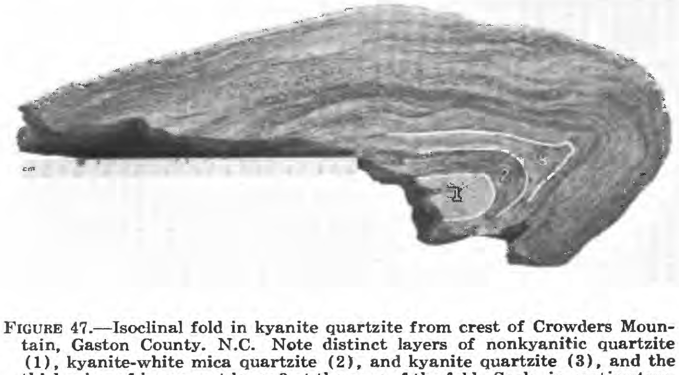


FIGURE 47.—Isoclinal fold in kyanite quartzite from crest of Crowders Mountain, Gaston County. N.C. Note distinct layers of nonkyanitic quartzite (1), kyanite-white mica quartzite (2), and kyanite quartzite (3), and the thickening of innermost layer 3 at the nose of the fold. Scale, in centimeters.

FIGURE 48.—Foliated kyanite quartzite at south end of The Pinnacle, Gaston County, N.C., looking southeast along base of cliff.

or sprays and flattened radial aggregates along the foliation planes. Individual blades are from 3 to 10 mm long; some radial sprays are as much as 8 inches in diameter, but these are rare.

In thin section the principal constituents are seen to be quartz, kyanite, and, locally, white mica. Common accessory minerals are white mica, rutile, pyrite, magnetite, and zircon. Rare accessory minerals include apatite, barite, lazulite, tourmaline, pyrophyllite, and dolomite. The groundmass consists principally of fine-grained (0.05 to 0.5 mm) quartz (fig. 14). The habit and appearance of kyanite vary from well-formed blades with few or no inclusions and regular crystal boundaries (rare) to typical irregular elongate crystals with varying amounts of inclusions (fig. 2). In quartzite from Henry Knob and some parts of Clubb Mountain, kyanite occurs as well-formed blades holding numerous quartz inclusions (fig. 8). Some kyanite crystals show the obvious effects of deformation: crystals are bent, fractured, and faulted. Irregular quartz embayments and fracture fillings characterize these deformed kyanite crystals. Rutile occurs as very small crystals generally evenly dispersed through the rock. Pyrite content is variable, but the mineral generally is present in at least trace quantities. At Henry Knob and other localities pyrite constitutes as much as 8 percent of the rock.

Chemical and spectrochemical analyses of kyanite quartzite ore from Henry Knob and kyanite-chloritoid quartzite from a small ridge about one mile south of Crowders Mountain village are given in table 3. The ore at Henry Knob consists almost entirely of quartz, kyanite, and pyrite but contains minor amounts of white mica and rutile.

The kyanite-chloritoid quartzite is a light-gray rock consisting of radial aggregates of chloritoid and coarse parallel prisms of kyanite in a groundmass of fine-grained quartz (fig. 14). This rock is interlayered with kyanite quartzite. Although staurolite and chloritoid occur in kyanite quartzite along the northern part of the east limb of the Sherrars Gap syncline, the rock represented by the chemical analyses occurs over a distance of only 200 feet. This rock has the following mode: Quartz 40 percent, kyanite 40 percent, chloritoid 17 percent, magnetite 3 percent, and minor amounts of andalusite, staurolite, rutile, and zircon.

FIGURE 49.—Complex folding in kyanite quartzite, Shelton property, Gaston County, N.C., looking southwest along trend of outcrop. Photograph by W. C. Overstreet.

Replacement of kyanite quartzite by clay is widespread in the central part of Clubb Mountain (pl. 8). A large volume of kyanite quartzite on the northeast side of Crowders Mountain (pl. 7) is replaced by dickite. The mineralogy and general microscopic character of the clay at Clubb Mountain resemble those at Crowders Mountain. Much minor shearing and faulting have occurred in the area of replacement at Crowders Mountain. In both areas replacement has taken place along a complex ramifying system of small veins; dickite has replaced quartz as well as kyanite. Locally the quartzite is completely altered to dickite. Andalusite is associated with the kyanite in these areas, and pyrite and goyazite (a strontium-aluminum phosphate) occur locally; the unaltered nature of pyrite and the close association of pyrite and goyazite with clay suggest that pyrite and goyazite formed at the time of alteration to clay. Local pseudomorphic replacement of kyanite by clay occurs at the north end of the Shelton property. Several thin sections of kyanite quartzite from other parts of the district indicate incipient replacement of kyanite by clay.

Quartz veins and irregular masses of coarse milky quartz are common in many kyanite quartzite deposits. Some of these veins apparently were introduced into cross fractures in the quartzite; some masses of quartz are conformable lenses and segregations in the foliated quartzite. In general these veins and masses of quartz carry little or no kyanite or other minerals. At a few places, as The Pinnacle, Crowders Mountain, and Clubb Mountain, kyanite occurs along the margins of the vein (fig. 25) or as radial aggregates in the quartz. Other minerals occurring sparingly in quartz veins at Clubb Mountain are lazulite, ilmenite, and the calcium aluminum phosphate crandallite. Because more quartz veins occur in quartzite than in schist, and because all kyanite-bearing quartz veins are restricted to kyanite quartzite, it is thought that these veins and irregular masses of quartz were produced by metamorphic differentiation; hydrothermal fluids perhaps aided in mobilizing the materials.

SILLIMANITE QUARTZITE

Sillimanite quartzite occurs as thin lenses and beds within about 2,000 feet of the Yorkville quartz monzonite contact in the Crowders Mountain-Henry Knob area (pl. 7). Figure 42 shows the location of the sillimanite quartzite beds in this area; locally, these beds are gradational along strike with kyanite quartzite. A few short septa of sillimanite quartzite occur in the Yorkville quartz monzonite in this area.

In the Reese Mountain-Clubb Mountain area (pl. 8), sillimanite quartzite occurs as thin beds and lenses, principally at Reese Mountain and southwest of Machpelah Church.

Most sillimanite quartzite beds are from 10 to 30 feet thick. In highly folded areas, as at the Will Knox property, these beds are lenticular; in less deformed areas the beds are continuous along strike for as much as 3,000 feet. The beds are generally vertical and are surrounded by white mica schist that carries small and varying amounts of sillimanite, andalusite, and garnet.

Sillimanite quartzite is more resistant to weathering than the surrounding schist and crops out as low narrow ledges. Reese Mountain, about 150 feet high, is the most prominent hill underlain by sillimanite quartzite.

At many localities sillimanite quartzite is interlayered with, or in contact with, coarse-grained granular magnetite-bearing quartzite which carries little or no sillimanite. This rock is probably a metamorphosed sandstone or siltstone poor in clay.

Sillimanite quartzite is typically a light-gray rock. Sillimanite occurs as thin bone-white mats or flattened pencillike aggregates, varying from a few millimeters to about 3½ cm in length, evenly distributed through the quartz groundmass. These mats generally define a strong foliation in the quartzite, but in some places a massive structure is produced by the randomly oriented mats and anastomosing stringers of sillimanite. Each mat consists of extremely fine grained fibers of sillimanite (fibrolite). In general, sillimanite quartzite has less iron than kyanite quartzite.

Thin-section study of sillimanite quartzite indicates little compositional variation between the different beds or deposits. The principal minerals are quartz, sillimanite, and, in several places, andalusite. Kyanite and diaspore are major constituents locally. Common accessory minerals are rutile, white mica, magnetite, and pyrite. Rare accessory minerals include lazulite, topaz, zircon, chloritoid, and apatite; lazulite is locally abundant at a few places.

The mats and aggregates of sillimanite are seen in thin section to consist of radiating aggregates of fibrolite, each prism being 0.04 to 0.2 mm long and less than 0.004 mm wide (fig. 15). Coarse prisms of sillimanite, about 2 mm long and from 0.05 to 0.09 mm wide, are intergrown with the fibrolite. Both varieties of sillimanite are generally intimately intergrown with quartz (figs. 15, 16); very fine grinding would probably be necessary to separate sillimanite and quartz by flotation (see description of Will Knox property, p. 90). Sillimanite generally constitutes from 10 to 35 percent of the rock.

Andalusite is a common major constituent in certain sillimanite quartzite deposits (fig. 16). It locally makes up as much as 60 percent of the rock. Kyanite and diaspore occur sporadically in sillimanite quartzite, and are rather abundant locally. In every place where two or more aluminous minerals occur together it seems that the order of formation from oldest to youngest was andalusite, kyanite, sillimanite, and diaspore. Incipient alteration of all these minerals to clay occurs locally in some deposits.

Table 3 gives the chemical and spectrochemical analyses of sillimanite quartzite from two deposits. The alumina in these analyses is a direct indication of the amount of sillimanite (or combined sillimanite and andalusite) in the rock because very little mica is present.

Massive aggregates of fibrolite, measuring 4 inches to 1 foot in greatest dimension, occur commonly as float near sillimanite quartzite that crops out along the margins, and within the main body of the Yorkville quartz monzonite. In thin section these aggregates are seen to consist of randomly oriented swirling mats of fibrolite; rutile is an abundant and common accessory. Small pods of cream-colored hard waxy clay occur within the fibrolite aggregates, but the clay apparently did not replace sillimanite.

YORKVILLE QUARTZ MONZONITE

A coarse-grained quartz monzonite, named the Yorkville granite by Keith and Sterrett (1931) from its occurrence at York (formerly known as Yorkville), S. C., crops out along the east margin of the Crowders Mountain-Henry Knob area, and separates the metamorphic rocks in this area from those in the Reese Mountain-Clubb Mountain area to the northeast (fig. 41). The rock is here renamed the Yorkville quartz monzonite. It is placed in the quartz monzonite or adamellite family of Johannsen (1932) because its orthoclase: plagioclase ratio is about 35:65.

The main body of the Yorkville quartz monzonite is more than 55 miles long; its width varies from about 2 miles at the north end to more than 7 miles at the south end. The extent of this body to the south and east was not determined. A smaller body of quartz monzonite lies south of the Crowders Mountain-Henry Knob area (pl. 7). Only a small part of the northern contact of this body was mapped in the present study.

The most common facies of the Yorkville quartz monzonite is coarse-grained medium- to dark-gray porphyritic quartz monzonite that has well-developed flow structure defined by parallel orientation of feldspar phenocrysts and biotite. This rock grades into nonporphyritic facies whose compositions range from granite to quartz monzonite.

Chemical, spectrochemical, and modal analyses of typical quartz monzonite in the Kings Mountain district are given in table 10.[10] Microcline forms large phenocrysts that are generally perthitic. Plagioclase (An_{25}–An_{38}) also occurs as phenocrysts and as smaller crystals in the groundmass; calcic oligoclase with zonal structure is the most common variety. Many thin sections of the quartz monzonite show an interstitial aggregate of albite or sodic oligoclase, quartz, and myrmekite. Myrmekite is best developed at the ends of tonguelike projections of sodic oligoclase into microcline. Biotite content is variable; rarely, hornblende occurs with biotite. Muscovite is generally present in small amounts.

Numerous dikes of aplite, pegmatite, and fine-grained quartz monzonite cut the main body of coarse-grained quartz monzonite. Pegmatite dikes, related to the Yorkville quartz monzonite, cut the metamorphic rocks as far as half a mile from the quartz monzonite contact.

An igneous origin for the Yorkville quartz monzonite is indicated (Potter, 1955) by the marked increase in metamorphism of country rock near the quartz monzonite; the presence in the surrounding country rock of pegmatite dikes mineralogically related to the quartz monzonite; structural deformation along the quartz monzonite contact; the presence in the quartz monzonite of zoned plagioclase and an interstitial aggregate of sodic plagioclase, quartz, and microcline suggesting a crystallization sequence; and the marked textural and mineralogical contrast between the quartz monzonite and surrounding country rocks.

It is probable that the Yorkville quartz monzonite was emplaced during Early Mississippian time, because the age of zircon from the quartz monzonite exposed 1.7 miles south-southeast of Henry Knob (sample collected by W. R. Griffitts) was deter-

[10] Watson (1910) records chemical analyses of granite from 2 quarries lying within the outcrop area of the Yorkville: the Whiteside quarry, 5.7 miles S. 15° W. from Henry Knob, and the Jackson quarry, 2.9 miles S. 74° E. from Henry Knob. These 2 analyses are included in table 10 and indicate a similar composition for the Yorkville throughout this area.

mined through the Larsen method by H. W. Jaffee (oral communication, 1956) as 260 million years, and because the quartz monzonite shows no signs of having been metamorphosed or altered by hypogene processes and therefore was emplaced during or after the last orogeny in this part of the Piedmont.

Numerous long thin septa of metamorphic rocks occur in the Yorkville quartz monzonite (pl. 7; fig. 42). These septa represent remnants of the metamorphic sequence on the east limb of the South Fork anticline (fig. 42). The principal metamorphic rocks in these various septa are biotite-sillimanite schist, biotite gneiss, sillimanite quartzite, garnet-quartz-biotite schist, manganiferous schist and fine-grained spessartite rock, pyroxene granulite, hornblende gneiss, and corundum gneiss. Minor amounts of anthophyllite gneiss and cordierite gneiss were found as float. The corundum gneiss is particularly interesting because corundum crystals are generally imbedded in muscovite or in microcline with a sheath of muscovite about the corundum (fig. 50). Corundum may have formed from aluminum released when muscovite was transformed to microcline. The sheath of muscovite surrounding the corundum is probably a still later reaction between corundum, microcline, and water.

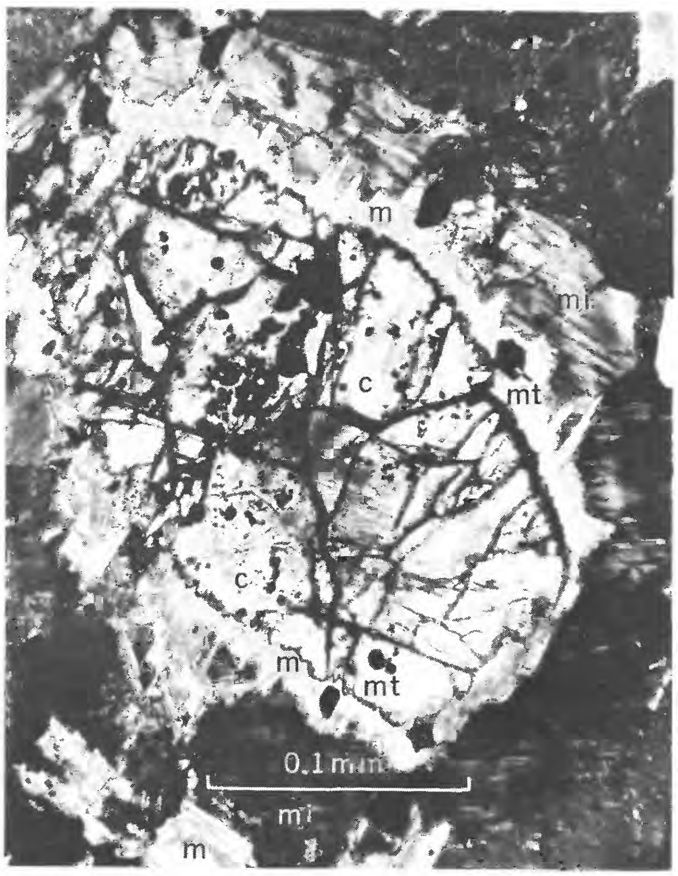


FIGURE 50.—Photomicrograph of corundum gneiss from septum 1.3 miles northwest of Pisgah Church, Gaston County N.C. The large euhedral crystal of corundum (c) is partially replaced by a sheath of muscovite (m). Other minerals are microcline (mi) and magnetite (mt). Crossed nicols.

DIABASE

Steeply dipping dikes of fine- to medium-grained diabase cut diagonally across the regional grain of the rocks in the Crowders Mountain-Henry Knob area (pl. 7). These dikes range from a few thousand feet to 4 miles in length and from a few inches to about 60 feet in width. They cut the metamorphic rocks at places where kyanite quartzite beds are very thin or absent. Diabase dikes cut the Yorkville quartz monzonite and have been intruded along the contact between the quartz monzonite and the metamorphic rocks. The composition and the texture of the diabase are uniform: the principal constituents are labradorite, augite, and olivine; ophitic texture is common. A Triassic age is assumed for the emplacement of the diabase because the dikes show no evidence of deformation and because they are petrographically identical to diabase dikes of known Triassic age.

STRUCTURE

Two major folds in the Crowders Mountain-Henry Knob area, the South Fork anticline and the Sherrars Gap syncline (pl. 7; fig. 42), are delineated by the distribution of the outcrops of high-alumina quartzite and manganiferous schist. The meager evidence for the synclinal and anticlinal nature of these folds has been summarized in the section on stratigraphy. In their southern parts the axes of both these folds trend N. 40° E. In the northern part the axis of the South Fork anticline turns northward and trends parallel to the contact of the Yorkville quartz monzonite. The anticline is asymmetrical—the east limb being nearly vertical and the west limb (east limb of the Sherrars Gap syncline) dipping steeply northwest. The South Fork anticline plunges north at probably a rather high angle. The Yorkville was emplaced into the east limb of the South Fork anticline with the result that many of the beds on the east limb persist as septa in the quartz monzonite.

The Sherrars Gap syncline, which plunges northeast in its southwestern half, has a sinuous trend. In the southern part the axis of this fold trends N. 40° E., in the middle, N. 60° E., and in the northern part, N. 10° E. The southern part of the syncline is overturned to the southeast with the axial plane dipping steeply northwest; in the central part of the fold the axial plane is vertical, and in the northern part the axial plane dips steeply east and the plunge is to the north.

Within the framework of these major folds the structure is speculative because of the uncertainty in correlating the lenticular beds of high-alumina quartzite. Two structural interpretations, based upon the existence of either one of these beds of high-alumina quartzite, are given below.

Interpretation 1, shown on plate 7, presupposes the presence of only one bed of high-alumina quartzite. The multiplicity of kyanite quartzite outcrops in the vicinity of Crowders Mountain is explained by refolding and faulting at the nose of the South Fork anticline. Faulting is suggested by the apparent offset of the kyanite quartzite beds in this vicinity, by the apparent truncation of schistose pyroclastic rock just east, and 1 mile southeast of Crowders Mountain, by the presence along the traces of the inferred faults of at least 5 zones of intense shear, and by the presence of fault breccia at 3 localities. Two of the faults, on the east and southeast side of Crowders Mountain, pass through zones of barite mineralization. These faults are for the most part parallel to the nearly vertical foliation, and the movement along the faults, judging from the apparent offset and from the few exposures of slickensides, is oblique slip (compare map and sections of plate 7). Such oblique-slip movement along vertical planes, whether faulting or distributed shearing, is probably very common in the area, particularly on the limbs of the tight folds. The longest fault in the area, extending through the Lawton barite mine, may pass into a high-angle reverse fault in the area east of Stepps Gap.

According to interpretation 1, the axis of the South Fork anticline is offset to the west on the north side of the fault that runs through the Lawton barite mine. No single axis for the South Fork anticline is shown on plate 7 north of this fault because the rocks have been highly folded. The axis of the South Fork anticline probably passes in the general vicinity of Crowders Mountain. The complex outcrop pattern of kyanite quartzite at Crowders Mountain and in the vicinity to the west and south are explained by steeply plunging folds with vertical axial planes (pl. 7). Small folds, with amplitudes and wave lengths from 1 to 20 feet, are extremely abundant in these outcrops of kyanite quartzite.

The Pinnacle gives another example of complex folding of kyanite quartzite (pl. 7, section *B–B′*; fig. 52). The foliation generally conforms to the outer margins of this mass of kyanite quartzite. Small randomly oriented folds are abundant and suggest considerable large-scale flowage of material during the folding and metamorphism. Such flowage is common in small folds in the area (figs. 47, 51). The structure of the kyanite quartzite at The Pinnacle is assumed to be a sharp anticline near the trough of the Sherrars Gap syncline.

FIGURE 51.—Small folds in fine-grained quartz-white mica schist, just east of dam at Crowders Mountain village, looking down on outcrop. Note that quartzose layers are greatly thinned on limbs of fold and thickened at noses. Scale. in inches. Photograph by W. C. Overstreet.

The long thin parallel lenses of kyanite quartzite and sillimanite quartzite along the east limb of the South Fork anticline from McGill Branch to the Ryan-Purcley property and at Henry Knob are assumed to be the tightly compressed limbs of an isoclinal syncline. Complex refolding of this syncline may account for the irregular outcrops at the Ryan-Purcley property, Will Knox property, and just south of McGill Branch. Numerous small southwest-plunging folds may account for the great number of small kyanite quartzite lenses southwest of Henry Knob.

Interpretation 2, shown in figure 42, presupposes the presence of 3 beds of high-alumina quartzite, each at a different stratigraphic position. The structural interpretation of the Sherrars Gap syncline and kyanite quartzite at The Pinnacle are the same as in interpretation 1. At Crowders Mountain and vicinity the outcrops of kyanite quartzite are accounted for by the presence of all 3 beds, the northern 2 being highly folded by 4 north-plunging folds with steeply dipping axial planes. No significant faults are postulated, but considerable shearing along vertical foliation planes undoubtedly took place. The parallel, and locally complexly folded, lenses of kyanite quartzite and sillimanite quartzits along the east limb of the South Fork anticline, including small septa in the Yorkville quartz monzonite, represent the three different high-alumina quartzite beds. At Henry Knob, bed *A* is folded into a highly compressed southwest-plunging fold.

Foliation (flow cleavage) is well developed and dips steeply; it is shown in the conglomerate beds by the parallelism of flattened pebbles (fig. 45) and elsewhere by the parallelism of platy minerals and mineral aggregates.

Pronounced lineation in the metamorphic rocks throughout most of the area is defined by small fold axes, crinkled foliation, elongate pebbles and various clastic fragments, slickensides, and minerals and mineral aggregates including kyanite, sillimanite, hornblende, biotite, feldspar, and pyrite. The three most common linear elements are small fold axes, prismatic minerals and mineral aggregates in high-alumina quartzite, and crinkles in schist. Small fold axes and minerals in the high-alumina quartzite lie within the plane of foliation and have a similar magnitude and direction of plunge in individual outcrop. In the area shown on plate 7, 93 readings on small fold axes show an average plunge of 49° and a range from 0° to 90°. In the same area 140 readings on minerals and mineral aggregates in high-alumina quartzite show an average plunge of 54° and a range from 0° to 90°. By contrast, 86 readings of crinkles in schist in the same area show an average plunge of 18° and a range from 0° to 70°.

In the quartzites south of McGill Branch, at the Shelton property, in the southern part of Crowders Mountain, and at Henry Knob the linear elements have a constant direction of plunge, perhaps parallel to the larger (not major) fold axes. In many localities neither the direction nor magnitude of plunge of linear elements in quartzite is constant, but these elements all lie in the plane of foliation. This variability of direction of plunge of small fold axes and mineral aggregates in the quartzites suggests that the linear elements formed in response to oblique-slip movement along steeply dipping bedding planes, shear planes, foliation planes, and faults.

In the few places where crinkled schist is observed actually in contact with high-alumina quartzite, the crinkles have the same magnitude and direction of plunge as the linear elements in the quartzite. This suggests that the deformation of the more rigid quartzites controlled the deformation of the adjacent schists. The fact that crinkles in schist throughout the area do not plunge so steeply as linear elements in quartzite suggests that the oblique-slip movement was not transmitted through the schists. The crinkles may have formed at approximately right angles to shearing along foliation planes as the schists were squeezed toward the surface.

The three principal linear elements show no signs of being deformed by later structures. They probably were formed contemporaneously during the last stage of deformation (see below).

Joints are numerous in the metamorphic rocks of the area. They are commonly vertical, or steeply dipping, and cross the foliation and bedding at right angles. In outcrops of high-alumina quartzite where small folds are numerous the joints are at right angles to the axis and axial planes. The very gently dipping tops of The Pinnacle and parts of Crowders Mountain reflect the presence of nearly horizontal joints.

Several lines of evidence suggest that the rocks in the Crowders Mountain-Henry Knob area have undergone two stages of deformation:

1. Where the Sherrars Gap syncline trends N. 40° E. and N. 60° E., kyanite quartzite on both limbs is transected by steeply dipping foliation which strikes N. 5° E. to N. 20° E.
2. The axis of the Sherrars Gap syncline has a sinuous trace, suggesting that the initial fold has been refolded.
3. Kyanite quartzite at the nose of the South Fork anticline, in the vicinity of Crowders Mountain, has apparently been refolded and, perhaps, faulted.

Dating of the stages of deformation is uncertain, but it appears that the major folds were formed with a N. 40° E. trend before the emplacement of the Yorkville quartz monzonite. If the rocks which constitute the metamorphic sequence in the Crowders Mountain-Henry Knob area are Ordovician or older, it is possible that the major folds were formed during the major Ordovician orogeny that affected the rocks over some 25,000 square miles of the Piedmont (Overstreet and Griffitts, 1955) just to the south, west, and north. However, it is possible that the rocks in the Crowders Mountain-Henry Knob area, characterized as they are by a lower rank of metamorphism than rocks elsewhere in this part of the Piedmont, were formed after the Ordovician orogeny. If this is true, the two stages of deformation were probably both related to the emplacement of the Yorkville quartz monzonite in Early Mississippian(?) time.

In either case, the emplacement of the Yorkville quartz monzonite was accompanied by intense shearing, folding, and, probably, faulting. This deformation probably accounts for all the later structures outlined above. Foliation, pronounced linear structures, and joints are probably largely related to the later deformation.

METAMORPHISM

The rocks in the Crowders Mountain-Henry Knob area show a marked increase in rank of metamorphism toward the Yorkville quartz monzonite. The quartz monzonite itself, however, is unmetamorphosed. The metamorphic facies and their distribution are shown in figure 42. In general, the rocks in the western part of the area belong to the greenschist facies (Turner, 1948); to the east, in the northern part of the area, this facies grades into the albite-epidote amphibolite facies, and this into the amphibolite facies.

The assignment of the fine-grained pelitic rocks in the western part of the area to the greenschist facies, rather than to the albite-epidote amphibolite facies, is problematical. The greenschist facies is suggested for these schists by the presence of the characteristic mineral assemblages listed below and by the absence, insofar as could be determined, of garnet. The first appearance, to the east, of garnet and abundant chloritoid marks the western boundary of the albite-epidote amphibolite facies. The first appearance of staurolite still farther east marks the boundary between the albite-epidote amphibolite and amphibolite facies. By comparing plate 7 with figure 42 it will be seen that the chloritoid schist unit crosses the boundary between the last two facies. Some chloritoid persists in this unit within the area of the amphibolite facies, and, though sampling is meager, it seems that staurolite becomes more abundant to the east.

The following mineral assemblages occur in the area.

Greenschist facies:

- albite-chlorite-white mica
- white mica-chlorite
- white mica-chloritoid
- kyanite-white mica

Albite-epidote amphibolite facies:

- chloritoid-chlorite-white mica
- albite-epidote-hornblende
- chloritoid-garnet-white mica
- kyanite-white mica

Amphibolite facies:

- biotite-garnet-oligoclase (with staurolite or microcline locally)
- hornblende-andesine or oligoclase-epidote
- kyanite-white mica (with or without staurolite)
- sillimanite-white mica
- garnet-sillimanite-biotite
- cordierite-andesine-sillimanite (rare)
- corundum-microcline-sillimanite (rare)

The rare assemblage of corundum-microcline-sillimanite, found in a septum in the Yorkville quartz monzonite, probably represents the highest rank of metamorphism attained in this area.

The presence of kyanite in the greenschist facies may be due to the fact that even here the temperature during metamorphism was sufficient to bring about the transformation—

$$\text{Clay} \rightarrow \text{kyanite} + \text{silica} + \text{water}$$

The silica (quartz) released may account for the poikiloblastic texture (fig. 8) of much of the kyanite. Whereas sillimanite probably formed in part from clay, its presence in rocks of more diverse composition than sillimanite quartzite (that is, biotite schist and gneiss), and the proximity of sillimanite-bearing rocks to the Yorkville quartz monzonite suggest that sillimanite also formed from the breakdown of such minerals as mica. The latter transformation probably was at a higher temperature than the metamorphism of clay to sillimanite.

Andalusite is present in schists immediately adjacent to many kyanite quartzite beds but not in the kyanite quartzite. This may reflect slight differences in the composition (presence of ferrous iron?) of the parent clays of these two polymorphs. On the other hand, andalusite may have formed initially in the quartzite and then was replaced by kyanite when the quartzites were intensely sheared and folded. Andalusite may remain in the schists because shearing stress was lower here than in the quartzite.

In several thin sections, two or more of the alumina silicate polymorphs are present, and generally one is seen to have partially replaced the other.

Throughout the district, the order of development (from oldest to youngest) is—

Andalusite → kyanite → sillimanite

It is thought that, rather than indicating a series of metamorphisms, these replacements represent a series of incompleted polymorphic transformations during one, or, perhaps, two periods of metamorphism.

If the rocks of the Kings Mountain belt were deformed in Ordovician time (see "Structure") it is almost certain that the regional metamorphism that attended this deformation (Overstreet and Griffitts, 1955) would have produced rocks of the greenschist and albite-epidote amphibolite facies in the Crowders Mountain-Henry Knob area. More intense dynamothermal metamorphism accompanied the emplacement of the Yorkville quartz monzonite in Early Mississippian(?) time. It is difficult, therefore, to determine whether the lower rank facies represent the effects of an earlier widespread regional metamorphism or the fringe effects of the later more localized dynamothermal metamorphism. If we accept the idea that Ordovician regional metamorphism affected the rocks of this area, it follows that the high-alumina beds may have been metamorphosed at this time to kyanite quartzite or andalusite quartzite, and that sillimanite formed from these during the later more intense metamorphism. There is no clear evidence that all sillimanite quartzite formed from kyanite quartzite, though there is local petrographic evidence indicating replacement of kyanite by sillimanite. On the other hand, nearly all deposits of sillimanite quartzite show relict crystals of andalusite. Partial replacement of chloritoid by staurolite was seen in a few thin sections of quartzite. Regarding the great bulk of kyanite in quartzite, the intimate association of kyanite with the later small-scale structural features, leaves no doubt that kyanite was formed or recrystallized during the later metamorphism. Perhaps the ragged anhedral form of much of the kyanite (fig. 2) in the area indicates a recrystallization of kyanite that formed during Ordovician time.

To summarize: The evidence for more than one period of progressive metamorphism is inconclusive. The metamorphic rocks have been deformed twice, and it is likely that they have also been metamorphosed twice. Inasmuch as the most intense metamorphism occurred late in the geologic history of the area, and was rather restricted in extent, the answer to the problem of polymetamorphism can best be obtained by detailed field and petrographic study of surrounding areas.

A minor, but widespread, retrogressive metamorphism followed the latest progressive metamorphism. This is shown by the partial alteration of biotite, garnet, chloritoid, and hornblende to chlorite, of andalusite to white mica and tourmaline, and of kyanite to dickite. All these alterations involved water which may have come, in part, from the residual fluids of the Yorkville quartz monzonite magma.

The albitization of volcanic rocks, now biotite schist and hornblende gneiss, in the vicinity of Trinity Church is thought to have preceded the metamorphism discussed above because it did not affect such highly susceptible rocks as kyanite quartzite and sillimanite quartzite. This albitization probably occurred in the late stages of emplacement of the tonalite.

GEOLOGIC HISTORY

The geologic history in the Crowders Mountain-Henry Knob area is summarized below, starting with the earliest event. The rock names in parentheses indicate the metamorphic rock derived from the parent rock.

Late Precambrian(?) or early Paleozoic(?):

1. Eruption of volcanic rocks: Soda felsite (bulk of biotite schist and gneiss), andesite and basalt (hornblende gneiss); deposition of conglomerate and other clastic sediments (conglomeratic biotite schist) which are interlayered with volcanic rocks.
2. Intrusion of tonalite (metatonalite and some biotite gneiss); local albitization of tonalite and rocks that are now biotite gneiss and hornblende gneiss.
3. Local intrusion of quartz gabbro (metagabbro) near Henry Knob.
4. Weathering and erosion(?).
5. Deposition of a thick sequence of clastic and pyroclastic sediments and eruption of volcanic rocks: Rhyolitic volcanic rocks and tuffaceous sediments (white mica schist and related schists and phyllite), pyroclastic and clastic material (schistose pyroclastic rock and schistose conglomerate of lower sequence), fine-grained sandy clays and intermediate volcanic rocks (chloritoid schist and biotite schist of lower sequence), manganiferous sediments (manganiferous schist).
6. Weathering and erosion(?).
7. Continued deposition of clastic and pyroclastic material and eruption of volcanic rocks: clay-rich silts, sands, and conglomerates (kyanite quartzite, kyanite conglomerate, kyanite-chloritoid quartzite, sillimanite quartzite conglomerate), ferruginous sandstone (ferruginous quartzite), pyroclastic material (schistose pyroclastic rock of upper sequence), basic volcanic rock (hornblende gneiss of upper sequence), and fine-grained sandy clays (chloritoid schist of upper sequence).

8. Period of major folds and regional metamorphism (both may be initial stage of next youngest event).

Early Mississippian(?):

9. Emplacement of Yorkville quartz monzonite accompanied by intense dynamothermal metamorphism.

Triassic:

10. Emplacement of diabase dikes.

Post-Triassic:

11. Long period of weathering and erosion.

KYANITE DEPOSITS

The principal kyanite deposits in the district are Henry Knob, the Shelton property, The Pinnacle, Crowders Mountain, and Clubb Mountain. Ore reserves in these deposits minable by open-pit methods are estimated to be 40 million tons of rock containing between 10 and 30 percent kyanite.

HENRY KNOB

Henry Knob is a small isolated conical hill located in York County, S.C., in the southern part of the Crowders Mountain-Henry Knob area (pl. 7; fig. 42). The crest of the hill stands about 340 feet above the surrounding Piedmont surface.

The earliest recorded shipment of ore from Henry Knob was in 1935, when B. J. Lachmond (or Lockmund) shipped some handpicked cobbles and smaller masses of coarse kyanite aggregates. This type of kyanite was found as float on the east slope and fields just to the east of Henry Knob. The property was leased by the Phosphate Recovery Corp. in 1939, but no mining was done until 1948 when the property was taken over by Commercialores, Inc. This company has produced kyanite concentrates continuously since then. Kyanite quartzite is mined from open pits at the crest and northeast slope of the hill, and the ore is trucked to the plant where it is crushed, ground, and a separation is made by flotation. The plant capacity is about 1,000 tons of kyanite concentrates monthly. Both raw kyanite and mullite are produced in sizes ranging from 35- to 200–mesh. Mining and processing techniques at Henry Knob are summarized by Avery (1953a).

Kyanite quartzite occurs here as steeply dipping lenticular beds (pl. 10). The major structure is that of a series of southwestward-plunging isoclinal folds, with very steeply dipping axial planes. This structure is suggested by the fact that kyanite quartzite beds terminate abruptly on the north slope of Henry Knob but extend for about 1.7 miles southwest from the crest of the hill (pl. 7). Linear structures and detailed map patterns (pl. 10) also suggest southwestward-plunging isoclinal folds. To the southwest, the beds thin, become highly lenticular locally, and, in general, carry more white mica than do the lenses at the crest of the knob. Small scattered lenses of kyanite quartzite occur southeast and northwest of Henry Knob (pl. 7; fig. 42).

The principal ore bodies at Henry Knob, where the Commercialores, Inc., mine is located, are shown on plate 10. The ore occurs in two long lenses arranged in echelon, which may represent the thickened limbs of isoclinal folds (pl. 10, sections *A–A′* and *B–B′*). On the southwest slope, kyanite quartzite occurs as many thin parallel lenses and beds; here one or two beds have probably been repeated by parallel folds. Kyanite quartzite is interlayered and infolded with pyritic white mica schist that contains minor amounts of kyanite, andalusite, staurolite, and tourmaline. Kyanite is abundant in this schist near the beds of kyanite quartzite; this kyanite schist is mined as ore in places. A diabase dike about 60 feet thick cuts northwesterly across all the rocks on the southwest slope of the hill.

The typical kyanite quartzite ore is tough, gray, and massive to well foliated. Kyanite commonly occurs in irregular branching seams extending through the quartzite matrix (fig. 4). Clots of coarse-grained randomly oriented kyanite, measuring from 6 to 12 inches in diameter, occur sparingly in an otherwise homogeneous ore. A strong joint system causes the ore to break into blocky fragments.

The principal constituents of the ore are quartz, kyanite, and pyrite. The texture and composition of the ore are uniform throughout the deposit. Rutile is a common accessory mineral; minor accessory minerals include white mica, pyrophyllite(?), lazulite, and barite. Table 3 gives a chemical and spectrochemical analysis of typical kyanite quartzite ore. This analysis indicates a kyanite content of 27.0 percent. Nine thin sections of ore from Henry Knob have the following average mode: Quartz 65.5 percent, kyanite 27.6 percent, pyrite 6.9 percent, minor amounts of rutile, white mica, and barite. Samples from core drilling to a depth of 200 feet indicate a rather uniform composition of the kyanite quartzite.

Kyanite generally occurs as subhedral blades up to 1 cm long, and commonly has numerous inclusions of quartz; some kyanite blades are riddled with small quartz inclusions. The origin of these inclusions is problematical. Smith and Newcome (1951) point out that inclusions are more abundant at the margins of the blades than at the cores and propose this as evidence that kyanite has replaced quartz. Some microscopic evidence (Potter, 1954) suggests that quartz has replaced kyanite, and it may be that many of the quartz inclusions represent the silica that was released when clay was metamorphosed to kyanite.

The groundmass consists of fine-grained (0.5 mm in diameter) quartz. Rutile occurs as fine grains and aggregates generally clustered in the kyanite. Pyrite occurs as small pyritohedrons disseminated fairly evenly through the rock, along tenuous fractures in quartz, and locally as interstitial wedges between kyanite blades.

Newcome[11] and Smith and Newcome (1951) propose that the alumina in kyanite quartzite at Henry Knob is of hydrothermal origin. The present study has revealed no direct evidence to indicate a hydrothermal origin (Potter, 1954), and the Henry Knob deposit, as well as the others in the district (see origin of kyanite quartzite, p. 24), is thought to be metamorphosed clay-rich sands or silts.

SHELTON PROPERTY

At the Shelton property, 1.6 miles east of The Pinnacle, Gaston County, N.C., kyanite quartzite occurs in irregular and highly lenticular outcrops (pls. 7, 11). These outcrops underlie a ridge some 50 feet high, which extends 1.7 miles southwest from a major tributary to Crowders Creek.

The outcrops here form the southeast limb of a plunging anticline, according to interpretation 1 (pl. 7); or bed *A*, according to interpretation 2 (fig. 42).

As shown on plate 11, kyanite quartzite is interlayered with ferruginous quartzite which contains magnetite, small amounts of staurolite, and only minor amounts of kyanite. Both types of quartzite have been intensely folded (fig. 49); the axes of these folds, and other linear elements, such as kyanite blades, plunge from 20° to 60° to the south. The axial planes of the folds dip steeply. The plunging and irregular nature of the folds doubtless mean that the kyanite quartzite bodies are as lenticular at depth as at the surface. Fine-grained white mica schist with small and variable amounts of andalusite and tourmaline surrounds the quartzite outcrops.

Kyanite quartzite here is typically well foliated, and the kyanite, which occurs as coarse-tufted aggregates (fig. 5), radial sprays and cones, and as single blades, is estimated to make up 25 to 30 percent of the rock. The intimate association of ferruginous quartzite with kyanite quartzite greatly reduces the amount of kyanite in the quartzite deposit as a whole.

In thin sections of kyanite quartzite, the quartz groundmass is seen to be coarser grained than at Henry Knob, and, in general, the kyanite does not hold as many quartz inclusions as that of Henry Knob. Accessory minerals include white mica, magnetite, and rutile. Kyanite is locally pseudomorphically replaced by a clay mineral of the kaolin group, probably dickite.

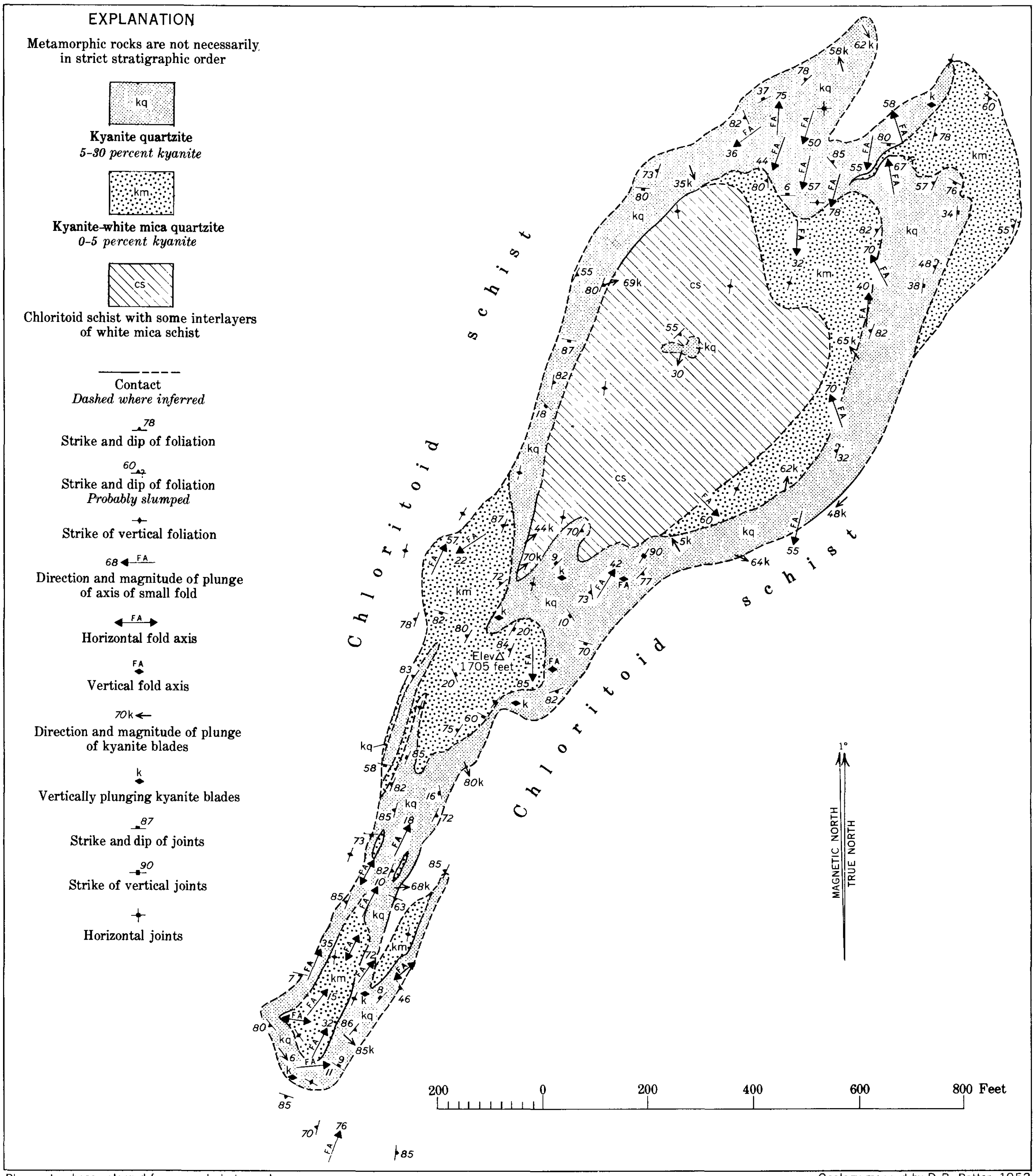
THE PINNACLE AND VICINITY

The Pinnacle is a narrow flat-topped ridge with summit elevation of 1,705 feet, located in the northwestern part of the Crowders Mountain-Henry Knob area (pl. 7, figs. 42, 52). The Pinnacle is the highest monadnock in this part of the Piedmont, and its bold cliffs and rugged craggy crest make it a conspicuous landmark. The total relief is about 700 feet along the ridge southwest of the summit and about 500 feet to the northeast of the summit. The upper 60 to 100 feet of the sides of The Pinnacle consist of very steep to vertical cliffs. The lower slopes are heavily mantled with talus of kyanite quartzite.

The kyanite quartzite beds at The Pinnacle, which lies in the Sherrars Gap syncline, are undoubtedly the same ones that crop out on the limbs of the syncline. These kyanite-bearing beds on both limbs of the syncline southwest of The Pinnacle are largely conglomeratic and generally occur as 2 parallel layers separated by 20 to 100 feet of chloritoid schist. In many places kyanite conglomerate grades along strike to kyanite quartzite and to kyanite schist. In the conglomeratic rock, kyanite occurs as thin-matted aggregates interstitial to the white quartzite pebbles. Pyrite is a common accessory mineral. Kyanite content is generally less than 10 to 15 percent, but in 2 highly folded areas, where the beds are considerably thickened, it is higher than average. One of these areas is at the crest of the Kings Mountain ridge, 2,000 feet north of Sherrars Gap; the other is at a prominent hill, 3,300 feet southwest of Sherrars Gap (pl. 7).

Kyanite quartzite at The Pinnacle is thought to represent a locally thickened and highly folded segment of the beds near the crest of a sharp doubly plunging anticline in the trough of the Sherrars Gap syncline (pl. 7, section *B–B′*). Chloritoid schist, lying between the two kyanite quartzite layers on the west limb of the syncline, apparently was in part sheared or faulted out from between similar layers at The Pinnacle.

[11] Newcome, R. C., 1949, Kyanite at Henry Knob, South Carolina: Master of Science thesis, South Carolina Univ.



Planimetric base enlarged from aerial photograph

Geology mapped by D.B. Potter, 1952

FIGURE 52.—Geologic map of The Pinnacle, Gaston County, N.C.

Well-developed foliation (fig. 48) is parallel to bedding, and, in general, dips steeply and conforms to the shape of the quartzite outcrop. This is particularly true at the south end of the deposit.

Small randomly oriented folds, with amplitude and wave length from 1 to 15 feet, are abundant throughout the kyanite quartzite of this deposit. The gently plunging and horizontal small fold axes in the high southern half of the mountain (fig. 52) suggest that the anticlinal axis there may be virtually horizontal. The northern half of the mountain, lying some 150 to 200 feet below the summit, is underlain by chloritoid schist which is surrounded by kyanite quartzite. In the northern half of the deposit, linear elements in kyanite quartzite plunge inward towards the enclosed chloritoid schist, suggesting that the quartzite beds converge at depth.

Figure 52 shows that the kyanite content is highly variable throughout the deposit. The boundaries between quartzite containing 5 to 30 percent kyanite and quartzite containing 0 to 5 percent kyanite are not well defined. The largest concentration of kyanite is at the northeast end of the deposit where kyanite seems to constitute more than 20 percent of the rock.

Kyanite quartzite at The Pinnacle contains abundant limonite. At some places limonite forms a hard outer rind which promotes cavernous weathering of softer rock beneath. Most of the limonite was derived from the weathering of small disseminated crystals of pyrite.

Thin-section study of kyanite quartzite from this deposit indicates that kyanite occurs as subhedral to irregular anhedral crystals. Individual blades or grains of kyanite hold few quartz inclusions, but generally have irregular contacts with quartz; not uncommonly the kyanite blades are bent, fractured, and faulted. Some lenticular bands of coarse-grained quartz in the groundmass may represent highly flattened quartzite pebbles. Accessory minerals include white mica, pyrite, magnetite, rutile, zircon, and apatite.

CROWDERS MOUNTAIN

Crowders Mountain, located in the northern part of the Crowders Mountain-Henry Knob area and about 4 miles east of the city of Kings Mountain, is a long high craggy ridge. The relief ranges from about 25 feet at the south end of the ridge where the kyanite quartzite outcrop is narrow (pl. 7; fig. 42) to about 750 feet at the middle of the ridge where the quartzite outcrop is widest. The shape of the ridge is accurately shown by the shape of the quartzite outcrop. The north nose of Crowders Mountain has a relief of about 550 feet. Sheer cliffs, 100 to 150 feet high, occur along the east and west side of the mountain north of the radio tower.

Two principal types of quartzite are interlayered at Crowders Mountain, kyanite quartzite and massive ferruginous quartzite with generally only minor amounts of high-aluminous minerals. The individual outcrops have a northerly strike and very steep dip, and are intensely folded. The amplitude and wave length of these folds range from a few inches (fig. 47) to several hundred feet. In the southern half of the mountain the small fold axes and kyanite blades plunge consistently to the south; throughout the northern part most linear elements plunge to the south, but some plunge north and some are horizontal.

As the overall structure of the quartzites in the vicinity of Crowders Mountain is not well known, two structural interpretations are given. Both interpretations assume that the thick quartzite outcrops mark the approximate position of the nose of the north-plunging South Fork anticline.

Interpretation 1 (pl. 7) presupposes that the quartzite outcrops represent a single quartzite bed repeated by faulting and folding. These folds, steeply plunging anticlines and synclines with nearly vertical axial planes, were presumably superposed on the South Fork anticline.

Brecciated schist, cemented with limonite, occurs at the north end of Crowders Mountain along the fault that borders the mountain on the east. Shear zones occur in the zone of dickite alteration on the east side of the mountain and along the fault one-quarter mile west of the radio tower.

Interpretation 2 presupposes the presence of three quartzite beds at different stratigraphic positions (fig. 42). Bed *A*, the oldest, crops out at the Shelton property and along a low ridge southwest of the Lawton barite mine; bed *B* crops out about one-half mile west of the Shelton property and constitutes the main thick outcrops in the southern and central part of Crowders Mountain; bed *C* is represented by the long lenses of kyanite quartzite in the northern part of the mountain.

Most of the quartzite exposed in the central and southern parts of Crowders Mountain is a massive gray ferruginous quartzite with little or no kyanite. Magnetite and staurolite are locally very abundant in this rock. Two thin sections of the staurolitic quartzite have the following estimated modal range:

	Percent
Quartz	45–70
Staurolite	15–35
Kyanite	0–10
Chloritoid	0–5
Magnetite	7–8
Pyrite	0–9
Pale-green biotite	0–1

Andalusite is locally abundant at 1 place in the quartzite that contains 50 percent magnetite. This magnetite-rich rock has been prospected near the center of the mountain. About 1,000 feet southwest of the radio tower a lens of hematite schist 20 feet thick is interlayered between ferruginous quartzite and schistose pyroclastic rock. The hematite schist consists of about 70 percent specular hematite and 30 percent quartz.

The principal occurrences of kyanite quartzite are at the southern tip of the mountain, in the middle of the mountain south and east of the radio tower, and at the north nose of the mountain.

Individual kyanite quartzite beds in the southern part of the mountain are between 10 and 65 feet thick. Kyanite occurs typically as coarse-tufted aggregates which make up from 5 to 30 percent of the rock.

In the center of the mountain, kyanite quartzite occurs as massive units ranging in thickness from 100 to 600 feet. The kyanite content in these strongly foliated units is variable, and, in general, not so great as at the north or south end of the mountain. Kyanite quartzite is locally gradational with kyanite-white mica schist. Small folds (fig. 47) are most abundant in kyanite quartzite in this part of the mountain. Figure 2 shows the typical appearance of this kyanite quartzite in thin sections.

The areal extent of the dickite alteration on the east side of Crowders Mountain is not well defined; it may pinch out along foliation planes south of the area shown on plate 7. Some of the kyanite quartzite just west of the radio tower has been partially altered to clay. The petrology of the altered rock has been described under the general discussion of kyanite quartzite in this district.

The irregular beds and long lenses of kyanite quartzite at the north nose of Crowders Mountain contain variable amounts of kyanite. The highest kyanite content is found in the small lens and northernmost bed at the crest of the north nose. A few thin layers of coarse-grained randomly oriented kyanite occur in quartzite on the north slope of the mountain. These layers generally consist of more than 90 percent kyanite, but they are discontinuous and never more than 6 inches thick.

Several types of white mica schist surround the quartzite outcrops at Crowders Mountain. In general, the schist is highly weathered with the result that many of the dark minerals are unrecognizable. Andalusite-bearing schistose pyroclastic rock occurs at several places along the east side of the mountain. Staurolite-kyanite-white mica schist occurs locally at the south end of the mountain.

A few scattered lenses of kyanite quartzite occur with ferruginous quartzite on a long low ridge about half a mile east of the south end of Crowders Mountain. The largest kyanite quartzite lens, located about 0.3 mile southwest of the Lawton barite mine, is 400 feet long and 20 feet wide. Kyanite here resembles that at the south end of Crowders Mountain.

SPENCER MOUNTAIN

Spencer Mountain, about 4½ miles northeast of the center of Gastonia (fig. 41), is a prominent knob (1,304 ft altitude) that rises nearly 500 feet above the countryside. Fine-grained quartzite, micaceous quartzite, and quartz-mica schist are well exposed in an abandoned quarry on the south side of the mountain. Kyanite occurs as minute white crystals in very minor amounts in the quartzite and schist.

CLUBB MOUNTAIN

Clubb Mountain (also called Chubb Mountain) is in the eastern part of the Reese Mountain-Clubb Mountain area (fig. 41), about 2 miles east of Alexis. The Lincoln County-Gaston County line crosses the southern part of Clubb Mountain. This mountain is a low ridge extending for about 1½ miles in a northerly direction. The relief varies from 50 to 100 feet in the southern and central parts to about 150 feet at the north end where ledges are most prominent.

In general, kyanite quartzite occurs as a single steeply dipping bed along the central part of the ridge (pl. 8). Several parallel lenses occur at the north end of Clubb Mountain, and a few small scattered lenses occur north and south of it.

The principal occurrence of kyanite quartzite is in the lenses at the north end of the mountain (pl. 9). The shape of the outcrops and the echelon pattern of the two principal kyanite quartzite bodies along the crest of the ridge indicate repetition of one or more beds by folding. Small steeply plunging folds occur in some of the kyanite quartzite beds, but, in general, lineation is not strongly developed in the quartzite. A conspicuous steeply dipping flow cleavage in adjacent schist strikes north and is transected in several places by a steeply dipping slip cleavage with a northeasterly strike. Kyanite is locally abundant in this schist near the kyanite quartzite.

The texture and composition of much of the kyanite quartzite here are very different from other deposits in the district. Only small amounts of kyanite occur disseminated in the micaceous quartz groundmass; most of the kyanite occurs as sporadically distributed coarse-grained aggregates and clots ranging from 1 inch to 1 foot in diameter (fig. 6). Many of the aggregates are lenticular or rounded, but some are greatly elongated in the plane of foliation and appear to be thin layers in the quartzite. Coarse blue platy kyanite makes up from 40 to 90 percent of the aggregates. Other constituents, generally interstitial to the kyanite, are quartz, pyrophyllite, lazulite, and rutile. These coarse-grained aggregates are most abundant in the quartzite lens along the crest of the ridge, 600 feet north of the summit (pl. 9). Kyanite constitutes about 30 percent of this lens.

Thin sections of these coarse aggregates show the kyanite to be clear euhedral plates with few quartz inclusions. Incipient alteration to clay has occurred about the margins of kyanite crystals and along cleavage planes of kyanite. Pyrophyllite occurs in radiating aggregates interstitial to kyanite and in very thin veins cutting kyanite. Quartz occurs as small and large grains in the wedge-shaped interstices between kyanite blades. Some white mica is generally present.

The bulk of the kyanite quartzite in the northern part of Clubb Mountain is a massive to well-foliated rock containing less than 15 percent kyanite. White mica, pyrite, and rutile are common accessory minerals. Rutile crystals up to 1 cm long occur locally. Crosscutting quartz veins are common in the quartzite and many of these carry small amounts of lazulite. Crandallite occurs as small spheroidal aggregates near the border of one vein. Kyanite forms a comb structure along the margin and within the body of a large gently dipping quartz vein in the northwesternmost lens (fig. 25; pl. 9). The kyanite in the comb structure has an elongate euhedral habit whereas the kyanite in the quartzite just above the vein appears as ragged anhedra and shows evidence of having been deformed and partially recrystallized. Shearing has warped the vertical foliation planes in the quartzite into parallelism with the upper contact of the vein. It appears that the vein material was emplaced along a shear zone in the quartzite and that no deformation has occurred since its emplacement. The recrystallized kyanite in the quartzite suggests that alumina for the vein kyanite may have been derived by metamorphic differentiation.

Throughout the central part of Clubb Mountain (pl. 8), the kyanite quartzite is altered to clay. The degree of alteration varies from a few very thin veinlets in tough kyanite quartzite to complete replacement of kyanite and quartz groundmass by a system of small ramifying clay veins. The petrology of this alteration is similar to that at Crowders Mountain and is described in the general discussion of kyanite quartzite of this district. Minor amounts of sillimanite occur locally in the altered rock at Clubb Mountain.

At the south end of Clubb Mountain (pl. 8), in an area of poor exposures, the altered kyanite quartzite gives way rather abruptly to a lens of coarse-grained kyanite-pyrophyllite-lazulite rock, about 400 feet long and 80 feet wide. This rock consists of coarse (1 cm) plates of blue kyanite in random orientation with interstitial pyrophyllite, lazulite, and quartz. Pyrophyllite content ranges from 5 to 90 percent. Accessory minerals in this rock include rutile, pyrite, tourmaline, andalusite(?), diaspore, goyazite, and zunyite. In general, both major and accessory minerals are coarse grained and occur with euhedral form. Zunyite, a relatively rare aluminum silicate, occurs locally in pyrophyllite-rich rock as coarse (5 mm) euhedra.

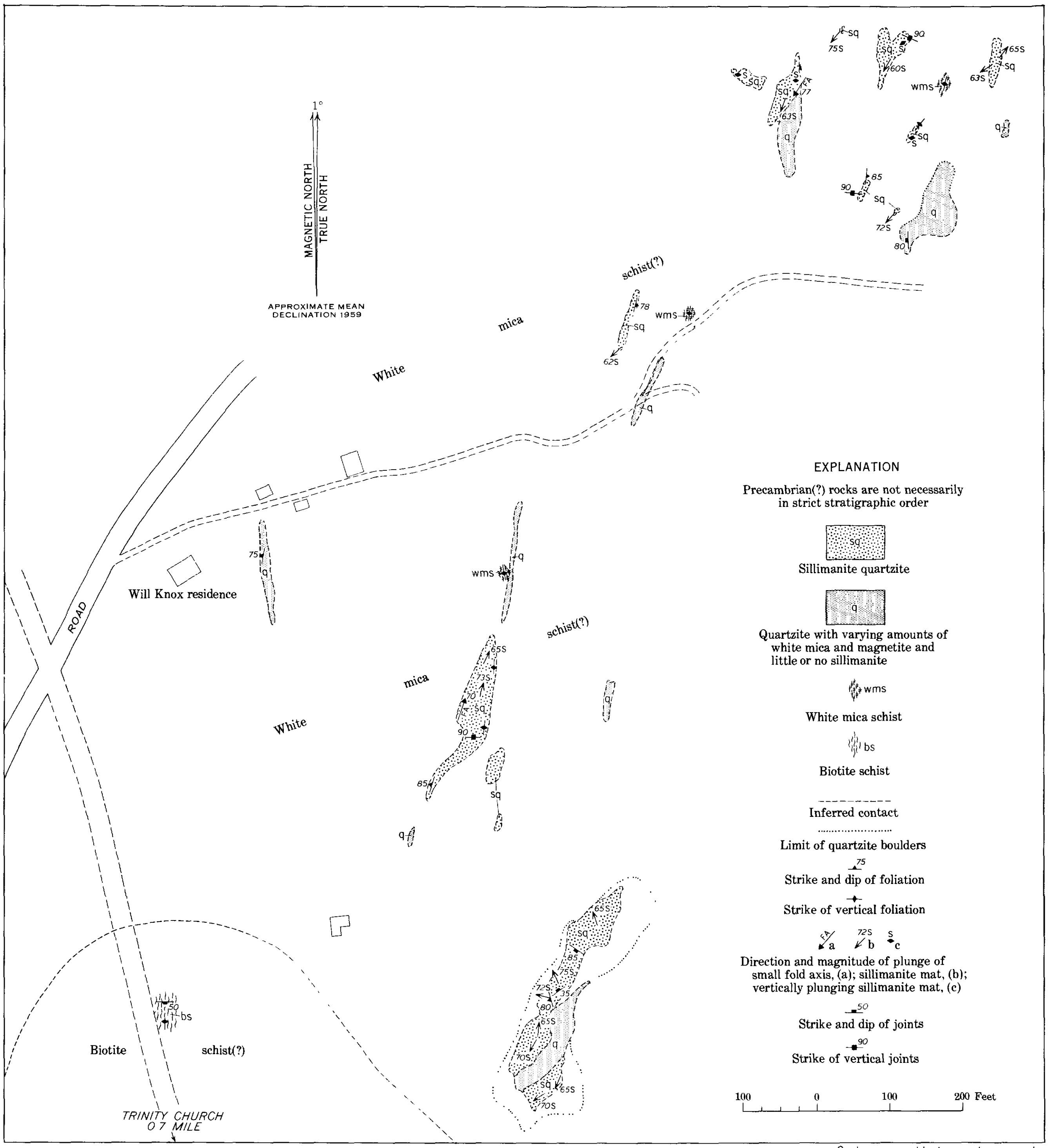
SILLIMANITE DEPOSITS

The major sillimanite quartzite deposits known in the district are on the Will Knox property, the Ryan-Purcley property, and at Reese Mountain. Ore reserves to a depth of 100 feet in the deposits in the district are estimated to be about 300,000 tons of indicated ore containing about 30 percent sillimanite.

WILL KNOX PROPERTY

The Will Knox property is in the eastern part of the Crowders Mountain-Henry Knob area in Gaston County, N.C. The principal outcrops are on 2 small hills 0.9 and 1.5 miles north of Trinity Church (pl. 7; figs. 42, 53). These hills are 40 to 60 feet high.

The sillimanite quartzite lenses here are locally thickened segments of a kyanite-sillimanite quartzite bed that extends north from the Will Knox property for about one mile (pl. 7; fig. 42). The thickening and the lenticular outcrop pattern (fig. 53) are the result of intense local folding. According to structural interpretation 1, this bed represents the



Geology mapped by tape and compass by D B Potter, March 1952

FIGURE 53.—Geologic map of the Will Knox property, Gaston County, N.C.

southwest limb of an isoclinal syncline, the northeast limb being sheared out in this area. Structural interpretation 2 indicates that the lenses here are bed *A*, and that bed *B* either is sheared out or was never deposited here.

The principal outcrop occurs on the crest of the hill 800 feet southeast of the Will Knox residence. Much of the rock is a massive gray andalusite-sillimanite quartzite with randomly oriented mats of fibrolite. At the south end of the outcrop, sillimanite quartzite is interlayered with a coarse-grained massive quartzite carrying only minor amounts of sillimanite.

The other principal outcrops at this deposit occur at the crest of a hill 1,200 feet northeast of the Will Knox residence. These outcrops are small and highly lenticular; the sillimanite quartzite is typically well foliated and lineated, and contains only small amounts of andalusite.

The composition and texture of the sillimanite quartzite vary from those of a massive gray rock in which coarse crystals and aggregates of andalusite (fig. 16) make up as much as 60 percent to those of a well-foliated quartzite with thin mats of sillimanite and very little andalusite. Generally, andalusite makes up less than 10 percent of the rock. Sillimanite mats are seen in thin section to consist of an intergrowth of fibrolite and coarse prisms with fibrolite dominant. Chemical and spectrochemical analyses of this quartzite are given in table 3. The mineral percentages, calculated from the analyses, are—

Quartz	53.8
Andalusite and sillimanite	43.1
Rutile	1.46
	98.36

Kyanite, diaspore, lazulite, and white mica are locally abundant in the sillimanite quartzite at the Will Knox property. Common accessory minerals are rutile and magnetite. Rare accessory minerals include apatite and zircon. Some of the rock is cut by very thin veins of clay, but, in general, the quartzite is unaltered.

Flotation tests made by the U. S. Bureau of Mines on a sample of sillimanite quartzite from this deposit showed that about 90 percent of the coarse prismatic sillimanite and 25 percent of the fibrolite could be recovered from material ground to pass 100-mesh (table 11). It was estimated that complete liberation of the fibrolite from quartz would require grinding to pass 5 microns.

The narrow beds of sillimanite quartzite that extend parallel to the west edge of the Yorkville quartz monzonite north and south of the Will Knox property (pl. 7; fig. 42) are characterized by scant sillimanite and variable amounts of white mica. The kyanite quartzite beds just south of McGill Branch consist of highly weathered quartzite with only small amounts of kyanite. A distinctive coarse-grained massive andalusite rock occurs locally between the two sillimanite quartzite beds north of the Will Knox property and on the hill just north of the principal outcrop. Coarse gray crystals of andalusite constitute from 65 to 95 percent of this rock; sillimanite occurs in the interstices between the coarse andalusite crystals.

RYAN-PURCLEY PROPERTY

The Ryan-Purcley property is located just north of the South Carolina border on the east side of the Crowders Mountain-Henry Knob area (fig. 42). The principal outcrop of sillimanite quartzite is at the crest and north slope of a sharp conical hill about 60 feet high (pl. 7). The outcrop pattern and lineation suggest that the sillimanite quartzite has been folded into a northward-plunging syncline. The nose of the fold is at the crest of the hill where the outcrop is about 160 feet wide. The west limb of this fold gradually thins towards the north over a distance of 1,000 feet; outcrops of quartzite terminate 300 feet south of the South Fork at Crowders Creek. Sillimanite quartzite on this limb is interlayered with white mica schist. The east limb

TABLE 11.—*Results of flotation test by U.S. Bureau of Mines on sillimanite quartzite from Will Knox property, Gaston County, North Carolina*

[Material ground to pass 100-mesh]

	Weight (percent)	Assay, percent						Distribution, percent					
		Prismatic sillimanite	Fibrolite	Quartz	Locked fibrolite and quartz	Mica	Rutile	Prismatic sillimanite	Fibrolite	Quartz	Locked fibrolite and quartz	Mica	Rutile
Cleaner concentrate	21.7	54.5	14.0	14.0	9.5	5.0	2.0	90.9	25.0	4.7	29.0	33.4	89.6
Middling	24.1	4.9	31.1	52.2	16.4	......	.2	9.1	61.6	19.3	55.8	......	10.4
Tailing	54.2	Tr.	3.0	91.0	2.0	4.0	Tr.	......	13.4	76.0	15.2	66.6	......
Total	100.0	13.0	12.2	65.0	7.1	3.3	0.5	100.0	100.0	100.0	100.0	100.0	100.0

of the syncline is represented by a long lens of coarse granular quartzite which carries only trace amounts of sillimanite. Small crystals of native sulfur occur locally in this quartzite.

Sillimanite quartzite at this locality is strongly foliated; its principal constituents are quartz, fibrolite and coarser sillimanite, and, generally, white mica. In thin section sillimanite is seen to be present largely in the form of fibrolite which is intimately intergrown with quartz (fig. 15). Rutile and magnetite are common accessory minerals; rare accessories include topaz, lazulite, and chloritoid. Diaspore occurs in a few pieces of float of massive sillimanite rock on the southeast slope of the hill. This rock contains more than 95 percent fine-grained chalky-white sillimanite.

A single steeply dipping bed of sillimanite quartzite from 3 to 15 feet thick extends 2,000 feet south from the Ryan-Purcley property.

REESE MOUNTAIN AND VICINITY

Reese Mountain, 2 miles north of Alexis in Lincoln County, N.C., is a sharp conical hill about 140 feet high (pl. 8) with low ledges just north of the crest. In this vicinity sillimanite quartzite, which is a well-foliated tough bone-white rock, occurs as 2 parallel discontinuous steeply dipping beds separated by about 40 to 300 feet of schist. The west bed is probably continuous for 3,000 feet, but it is poorly exposed and the outcrop pattern over much of this distance is based on scattered float. The east bed is thinner and more lenticular than the western bed. Sillimanite is more abundant in the west bed, especially in a lens about 50 feet wide and 250 feet long at the crest of Reese Mountain. No barren quartzite, such as occurs with other bodies of sillimanite quartzite, is exposed here.

The sillimanite quartzite from this lens consists principally of quartz and fibrolite. Chemical and spectrochemical analyses (table 3) show the similarity between this quartzite and that at the Will Knox property. The weight percentage of minerals from the lens at the crest of Reese Mountain is—

Quartz	61.9
Sillimanite	37.0
Rutile	.60
Magnetite	.2

Andalusite was not found in quartzite at the crest of the hill; diaspore occurs locally in sillimanite-rich float on the north slope.

Kyanite, andalusite, and sillimanite occur together in a quartzite lens 1,200 feet northeast of the crest and in lenses 4,200 feet southwest of the crest of Reese Mountain.

Sillimanite quartzite is interlayered with nonsillimanitic quartzite southwest of Machpelah Church (pl. 8). The tenor of this sillimanite quartzite is lower than that at Reese Mountain; the beds are lenticular and range from 10 to 30 feet in maximum thickness over a distance of 4,000 feet.

Small amounts of sillimanite and kyanite occur at the following localities west of Stanley Creek, which are not shown on plate 8. Poor outcrops of micaceous sillimanite quartzite occur at the crest of a small hill at Blair farm, 2.2 miles west of Stanley Creek. At another small knob just east of the road, 2.1 miles S. 60° W. of Stanley Creek, highly limonitized sillimanite quartzite, containing locally more than 30 percent sillimanite, crops out over a distance of about 50 feet. A few pieces of float of coarse platy kyanite, resembling that at Clubb Mountain, were found on the sharp knob just south of Mourney Creek, 0.4 mile south of the second sillimanite occurrence described above.

ORIGIN OF KYANITE QUARTZITE AND SILLIMANITE QUARTZITE

The following evidence suggests that the beds of kyanite quartzite and sillimanite quartzite in this district are metamorphosed sediments, probably clay-rich sands or silts.

1. Both kyanite quartzite and sillimanite quartzite have the distribution pattern and conformable nature of stratigraphic units (fig. 42).
2. Both types of quartzite exhibit compositional layering: kyanite quartzite is interlayered with staurolite quartzite, quartzite rich in white mica, ferruginous quartzite, and with thin layers carrying 90 percent kyanite; sillimanite quartzite is interlayered with coarse-grained nonsillimanitic quartzite.
3. Kyanite quartzite grades along strike to kyanite conglomerate, kyanite schist, and to chloritoid-staurolite quartzite.
4. Kyanite quartzite and sillimanite quartzite occur as thin beds in a sequence of high-alumnia sedimentary rocks. The high-alumina nature of these associated rocks (now schists) is indicated by abundant white mica and such minerals as andalusite, kyanite, sillimanite, staurolite, and chloritoid.

There is no evidence to indicate a hydrothermal source for the aluminum in the quartzites. Pegmatite dikes are virtually absent from much of the Crowders Mountain-Henry Knob area, and the distribution of kyanite quartzite deposits shows no apparent relation to the Yorkville quartz monzonite. Kyanite-quartz veins are found only in kyanite quartzite.

The distribution pattern of kyanite quartzite and the local compositional layering within the kyanite quartzite at Clubb Mountain suggest that here also the aluminum was indigenous to the sediment. The peculiar texture of the kyanite ore, the presence of numerous quartz veins locally containing lazulite and crandallite, and the presence in the ore of pyrophyllite and lazulite indicate that hydrothermal fluids were active in metamorphism here. The origin of the hydrothermal fluids is unknown, but it seems that their principal effect was to mobilize the aluminum already in the rock.

OTHER MINERAL DEPOSITS

The Kings Mountain district has long been known for its deposits of iron ore, barite, gold, and manganese. Pegmatites yielding commercial deposits of tin, spodumene, and mica (Keith and Sterrett, 1931; Kesler, 1942; Griffitts and Olson, 1953) are also of prime importance in this district; these deposits occur in a zone that extends through the city of Kings Mountain, 3 miles west of the Crowders Mountain-Henry Knob area.

IRON

The principal occurrence of magnetite in the Crowders Mountain-Henry Knob area is just west of Yellow Ridge (pl. 7). Here several deep pits were dug and ore produced during, or just before, the Civil War. This ore has a strong schistose structure; magnetite occurs sparingly on the dumps. Small amounts of magnetite also occur at the same stratigraphic position just south of Crowders Creek. Shallow prospects in white mica schist and biotite gneiss have been dug for magnetite 6,000 feet north of Henry Knob. Magnetite occurs commonly as small pieces of float in many parts of the area.

Thin lenses of specular hematite occur near the center of Crowders Mountain (p. 89). Many old prospects have been made for hematite and magnetite along the crest of the ridge.

The iron ore deposits of this region are more fully discussed by Nitze (1893) and by Keith and Sterrett (1931).

BARITE

The principal occurrences of barite are in a mile-long belt southwest of Gasset Lake (pl. 7). They are described under the headings, "Lawton property," "Craig property," and "Chimney place," by Van Horn, LeGrand, and McMurray (1949). These occurrences are part of the so-called Carolina barite belt extending from the vicinity of Gaffney, S.C., to the north end of Crowders Mountain. The Lawton property has been the most productive. Barite occurs typically as thin lenses along the foliation planes in schist. The present study indicates that barite mineralization at two localities was accompanied by local potash metasomatism. At these localities, thin veins of adularia and the pseudomorphic replacement of plagioclase by microcline attest to the introduction of potash in biotite schist.

MANGANESE

Little or no manganese has been produced from the Crowders Mountain-Henry Knob area. The principal occurrences of manganese are the manganiferous schist and accompanying fine-grained spessartite rock that occur as septa in the Yorkville quartz monzonite. Low-grade deposits of manganiferous schist occur north, southeast, and southwest of the Crowders Mountain-Henry Knob area (fig. 42); these have been described by Keith and Sterrett (1931) and by White (1944).

GOLD

Numerous small abandoned gold mines occur in the central part of the Crowders Mountain-Henry Knob area (pl. 7; Keith and Sterrett, 1931). For the most part these workings are overgrown and caved; limonitized country rock occurs on most of the dumps. Pardee and Park (1948) give brief accounts of the Patterson and Caledonia mines in the north-central part of the area. The abandoned Kings Mountain gold mine is located about 1 mile northwest of Lake Montonio.

SOUTH CAROLINA

CHEROKEE AND YORK COUNTIES

Kyanite quartzite occurs at Jefferson Mountain in Cherokee County, a small knob about 150 feet high lying 13 miles west-southwest of Henry Knob. It is one of the group of kyanite quartzite deposits in the Kings Mountain quadrangle (Keith and Sterrett, 1931), but lies southwest of the area shown on plate 7. Bare ledges of kyanite quartzite are exposed in an area several hundred feet in diameter on top of the knob. Most of the rock is very fine grained quartzite that is cut by thin stringers, generally less than an eighth of an inch thick, of kyanite; these outcrops have weathered to smooth rounded surfaces because of the low kyanite content. On the west side of the knob is a ledge, about 8 feet thick, containing veinlets several inches thick and irregular aggregates of coarse kyanite crystals; considerable limonite is present. The weathered surface of the ledge is rough and pitted because kyanite is rather abundant.

Kyanite-quartz rock occurs at another locality in Cherokee County south of Broad River, about 4 miles southwest of Jefferson Mountain and 0.8 mile northeast of Mt. Ararat Church. Here ledges of kyanite-quartz rock are exposed for a distance of about 50 feet and across widths of 10 to 15 feet. Veinlets of coarse blue kyanite crystals form a network in fine-grained quartzite; irregular quartz veins several inches thick cut the kyanite veins and the quartzite matrix. Kyanite, quartzite, and vein quartz are extensively replaced by fine-grained clay. On a low hill about a quarter of a mile to the southwest, float of kyanite-quartz rock is found over a distance of several hundred feet; no bedrock is exposed. The float rock contains abundant kyanite, generally as dark bluish-gray crystals less than a quarter of an inch long; some coarser kyanite is bright green. Magnetite is rather abundant in some of the rock. The occurrence of kyanite here is mentioned by Van Horn, LeGrand, and McMurray (1949) in their report on the barite deposits of this region.

Kyanite occurs in small quantities in fine-grained chloritoid-sericite schist on a low conical hill in York County, 3 miles west-southwest of Smyrna, and 1½ miles east of the Broad River (Keith and Sterrett, 1931). Microscopic examination shows the kyanite to be partly altered to sericite; considerable magnetite is present in some of the kyanite. Hornblende gneiss float is found on the hill, and sericitic quartzite with chloritoid is exposed in shallow trenches that were probably dug in search for gold; many gold prospects lie just to the east.

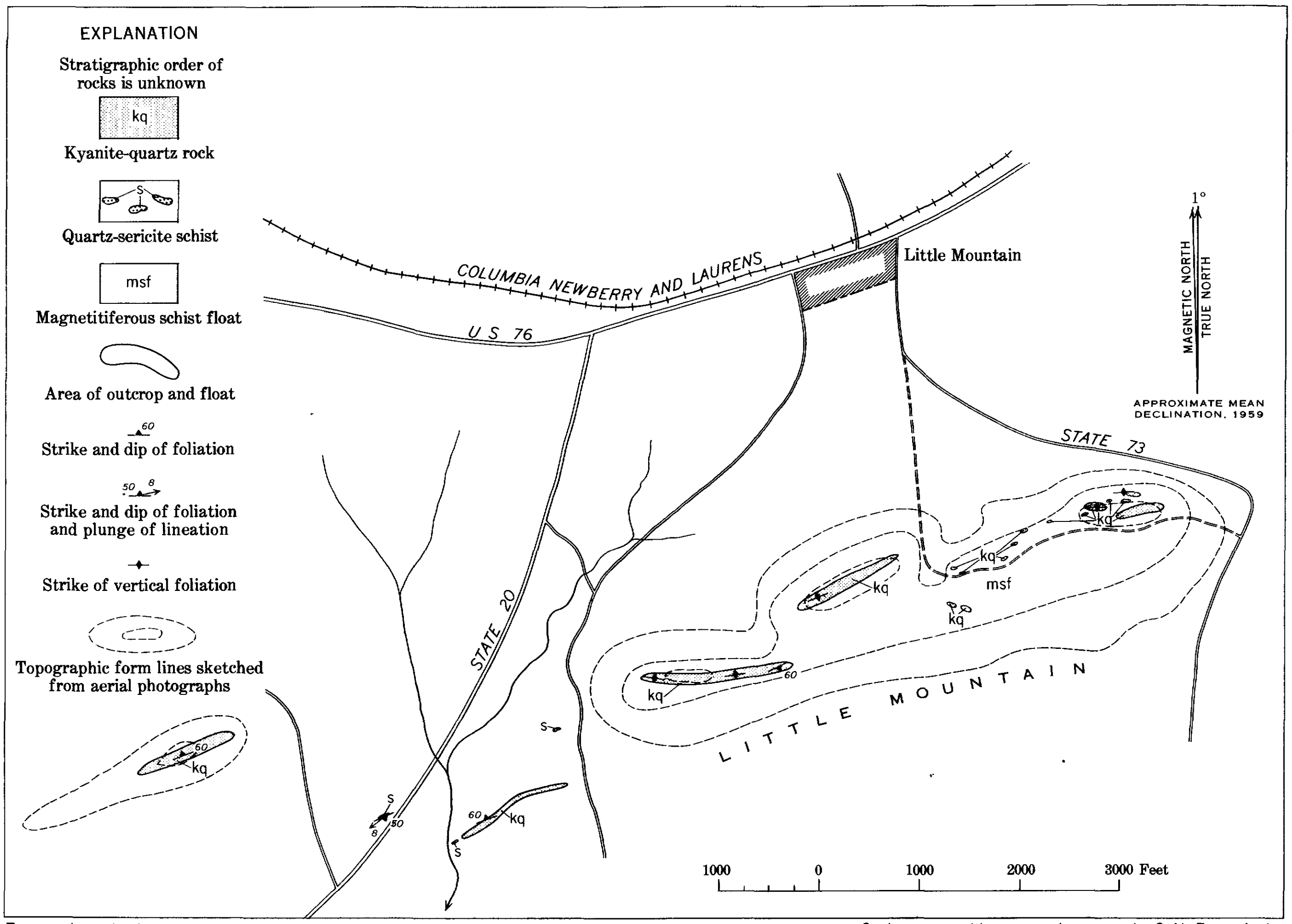
Kyanite quartzite occurs at Worth Mountain just east of Broad River in York County, S.C., about 17 miles southwest of Henry Knob and 8 miles due west of Sharon. The mountain is a northwest-trending ridge, about a quarter of a mile long, that rises nearly 100 feet above the surrounding country. The rock is a medium- to coarse-grained micaceous quartzite, heavily stained with limonite, and contains moderate amounts of small kyanite crystals. A few small aggregates of coarse kyanite are found at the crest of the ridge. The kyanite quartzite is exposed across widths of 10 to 20 feet in steeply dipping ledges a few feet high at intervals over a distance of several hundred yards. Near the crest of the ridge the ledges have an irregular zigzag trend, which is probably caused by tight folding of a thin bed of kyanite quartzite. A few irregular quartz veins cut the rock; 1 vein near the top of the hill has a selvage, 1½ to 2 inches thick, of long needlelike kyanite crystals at right angles to the contact. Fine-grained crinkled sericite schist at the south end of the mountain contains kyanite crystals that are from ¼ to ½ inch long. Shallow pits dug at several places on the ridge were probably prospects for gold.

LITTLE MOUNTAIN, NEWBERRY COUNTY

Kyanite-quartz rock underlies Little Mountain, Newberry County, in the eastern part of the South Carolina Piedmont. The ridge rises from 150 to 200 feet above the surrounding country and extends about 1¼ miles in a N. 70° E. direction; another lower and shorter ridge lies nearly three-quarters of a mile farther southwest along the strike. The kyanite-quartz rock occurs in several northeastward-trending belts, some of which are over 1,000 feet long and 100 to 150 feet wide (fig. 54). Outcrops are not continuous within these belts but consist of low ledges, a few feet high and as much as 20 feet long and 10 feet wide, that are distributed irregularly along the belts. The ledges dip steeply and trend in the same direction as the schistosity of the rock, between N. 70° and N. 85° E. The most conspicuous outcrops are on the west side of the middle knob of the mountain where steep ledges of kyanite-quartz rock are exposed across a width of about 150 feet.

The typical rock is a very fine grained schistose quartz rock that contains small crystals of bluish-green kyanite in thin veinlets, irregular stringers, and small aggregates. Under the microscope, the matrix of fine-grained quartz shows a strong gneissic texture of tiny elongated quartz grains with intricately sutured grain boundaries and strong undulatory extinction. Kyanite crystals have very irregular outlines and are full of quartz inclusions. Rutile grains, less than 0.5 mm across, are common in the rock. Fine-grained white mica is scattered through the kyanite-quartz rock. Analysis of coarse mica that occurs with a small mass of coarse kyanite shows the mica to be muscovite (sample SN5 in table 4). Most of the rock is stained with limonite, and in places has small cavities from which pyrite has been leached; pyrite is present in the freshest rock.

Veins of white quartz, a few inches to several feet in thickness, cut the kyanite-quartz rock. Thin stringers of kyanite and pyrophyllite accompany some quartz veins and cut the veins in several places. Microscopic examination shows that the ky-



Topography and culture from aerial photographs

Geology mapped by pace and compass by G. H. Espenshade, D. B. Potter, and P K. Theobold, Jr., May 1951

FIGURE 54.—Sketch map of geology of kyanite deposits, Little Mountain, Newberry County, S. C.

ante associated with vein quartz occurs as large well-developed crystals with few quartz inclusions; pyrophyllite stringers replace both kyanite and quartz. The amount of kyanite in the Little Mountain deposit is not readily estimated by visual inspection.

No other types of rock are exposed in the vicinity of the kyanite-quartz rock. Quartz-sericite schist crops out at several places southwest of the main ridge; it is possibly one of the major types of rock associated with the kyanite-quartz rock. Float of fine-grained magnetite-bearing schist occurs along the dirt road on the east half of the ridge.

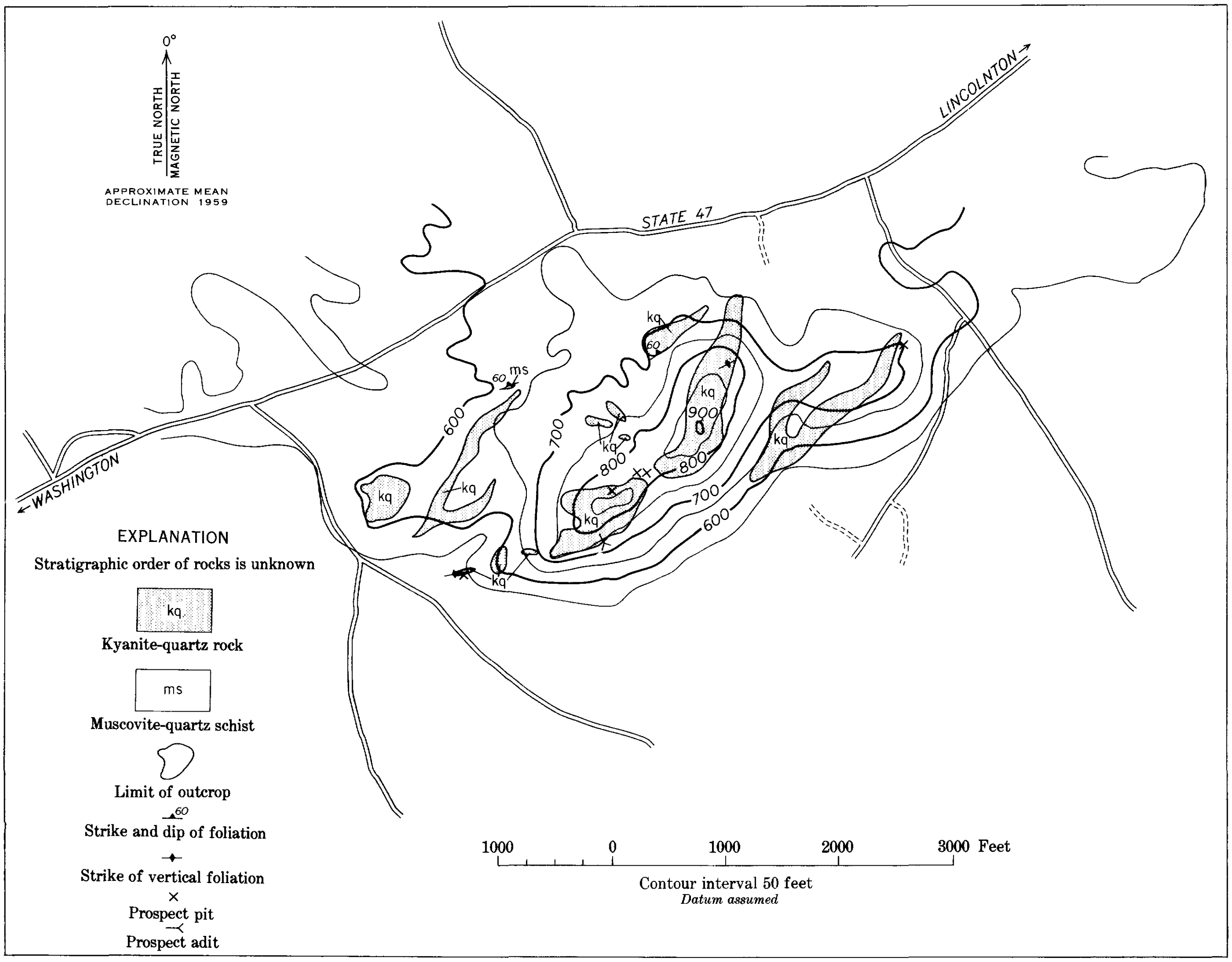
GEORGIA

GRAVES MOUNTAIN, LINCOLN COUNTY

Kyanite occurs in abundance in quartzose rock at Graves Mountain in western Lincoln County along Georgia Highway 47 between Lincolnton and Washington. Graves Mountain is a prominent ridge, about 1 mile long in a N. 60° E. direction and rising between 300 and 400 feet above the gently rolling countryside (fig. 55). The geology of the mountain has been described by Shepard (1859), who first called attention to the occurrence of pyrophyllite, rutile, and lazulite in the kyanite-quartz rock, and by Watson and Watson (1912), Johnston (Prindle and others, 1935), and Watkins (1942).

Some prospecting had been done for gold at Graves Mountain before the time of Shepard's visit in 1859. Later, several pits were dug on the saddle and the northwestern slope to recover rutile crystals.

The kyanite-quartz rock at Graves Mountain occurs in a number of large irregular lenticular bodies, some of which are 300 to 400 feet wide and as much as 1,800 feet long (fig. 55). Parts of several individual bodies seem to trend in 1 of 2 general directions: between N. 60° and 85° E., and between N. 20° and 30° E. These disconnected elongate bodies probably either represent the separated seg-



Topography compiled from aerial photographs by L. A Brubaker

Geology by G. H. Espenshade, 1953

FIGURE 55.—Geologic map of Graves Mountain, Lincoln County, Ga.

ments of closely folded and broken beds, or are replacement bodies that have been formed along two systems of fractures having these northeasterly trends. Watkins (1942) thought that the kyanite-quartz rock was in a tight syncline whose axial plane dips steeply northwest, and that there was possibly a fault along the southeast side.

The kyanite-quartz rock forms large bare massive outcrops and bold rough crags, 40 feet or more high; abundant talus mantles the slopes. Most of the rock is composed of very fine grained quartz with numerous thin stringers and scattered crystals and clots of small white to light-gray or green kyanite crystals. These kyanite stringers, generally less than half an inch thick, are closely spaced and parallel in places, but also form networks of randomly trending stringers. The clots and veinlets of kyanite stand out as rough projections and ribs on the weathered rock surfaces, the fine-grained interstitial quartz having been etched away to leave numerous small pits. Limonite is common in the weathered rock, generally in rather small amounts, but in places it is abundant and accompanied by dark-red earthy hematite; fine-grained pyrite is disseminated through the fresh rock. Considerable muscovite is present in the rock along the flanks and ends of the ridge.

Grains of bluish opalescent quartz, from 2 to 10 mm across, are very abundant in micaceous kyanite-quartz rock at the eastern and western ends of the ridge (fig. 1). Examination of loose grains of bluish quartz weathered from the kyanite-quartz rock showed that some of the grains seem to have bipyramidal crystal form, and it was suspected that the blue quartz grains might have originally been quartz phenocrysts. This conclusion was also reached by R. L. Smith after examining the blue quartz; he states (written communication 1953):

> Some of the blue quartz in these samples occurs in well-formed hexagonal bipyramidal crystals, some of which show poorly developed prism faces. Many of the blue quartz grains show several crystal faces while others have been altered to the point where they show no recognizable crystal form. It seems reasonable to assume a common origin for all of the blue quartz grains * * * .
>
> In my opinion the blue quartz in these samples was formed as a high temperature phenocrystic quartz in a high silica rhyolite. The blue color is probably not primary, but rather related to the later metamorphism. Possibly it is due to dispersion caused by the presence of tiny rutile needles.

Quartz veins are especially abundant along the southwestern part of the ridge as individual veins and networks of irregularly intersecting veins, which range in thickness from a few inches to more than 10 feet. Johnston (Prindle and others, 1935) has pointed out that kyanite is abundant along the margins of some quartz veins and decreases in amounts away from the veins. We have also observed some quartz veins in the kyanite-quartz rock that have no apparent concentration of kyanite along or near their margins.

Pyrophyllite seems to be most common in the area where quartz veins are numerous. It is light gray to tan, has a pearly luster, and forms aggregates of small granular crystals and clusters of radiating slender crystals about ¼ to ½ inch long. It occurs alone in crosscutting stringers about half an inch thick; it is found with quartz veins and in the adjacent wall rock, and also with coarse kyanite. In thin section, pyrophyllite is seen to have replaced kyanite. Watson and Watson (1912) state that masses of radiating aggregates of pyrophyllite several feet thick are well exposed in low cliffs along a road on the northwestern slope of the mountain.

Lazulite (an aluminum-rich phosphate) occurs as small blue crystals, generally less than half an inch in size, sparsely distributed through kyanite-quartz rock. It seems to be most common along the central part of the ridge, particularly where quartz veins are numerous, but it occurs in the kyanite-quartz rock rather than in the quartz veins. Johnston (Prindle, and others 1935) says that lazulite appears to be confined to a zone 2 to 3 feet wide extending in a N. 30° E. direction up the south slope of the hillside toward the saddle; it is common here but is not restricted to this zone. On some weathered surfaces, lazulite is altered to a claylike material that contains small blue specks of unaltered lazulite. Shepard (1859) and Watson (1921) described the occurrence of lazulite at Graves Mountain. Watson includes a chemical analysis of the mineral whose calcium oxide determination (3.12 percent) is evidently too high; a recent analysis (Pecora and Fahey, 1950) found 0.06 percent calcium oxide in a lazulite specimen from here.

Rutile occurs at Graves Mountain in exceptionally large and well-formed crystals that have been prized by mineral collectors since Shepard (1859) first described them. Multiple-twinned crystals are common; the largest crystal is said to have weighed about 4 pounds. The different forms of rutile crystals found here were described by several German crystallographers between 1860 and 1890; references to these articles may be found in Watson and Watson (1912) and Johnston (Prindle and others, 1935). The best rutile crystals were found in the saddle and on the northwestern slope in coarse kyanite-quartz rock containing considerable hematite and limonite. Several pits were dug to recover the mineral; according to Kunz (1907, p. 52) the value of the mineral specimens sold from here in the last century was about $20,000. Apparently the easily found large crystals were gathered up many years ago, because Watson and Watson (1912) state that they could find none at the time of their visits; a few rutile crystals, ½ to 1 inch long, can be found at present. Tiny grains of rutile are widespread throughout the rock as inclusions in kyanite and quartz.

Watson and Watson (1912) give the following partial analyses, in percent, of rocks from Graves Mountain:

	Schistose kyanite-muscovite quartz rock with limonite (from northwest slope)	Massive kyanite-quartz rock (from crest of mountain)
SiO_2	79.18	69.74
Al_2O_3	14.14	24.86
Fe_2O_3	3.17	.53

Several lines of evidence favor the replacement origin of the kyanite-quartz rock here. The abundant blue-quartz phenocrysts are among the strongest items of evidence. These blue-quartz grains must either be the relicts of quartz phenocrysts in a porphyritic igneous rock that has been completely replaced by silicon and aluminum, or they have been derived from a quartz porphyry by weathering and deposited as small pebbles in a clayey sand that was metamorphosed to kyanite quartzite. This second (detrital) mode of origin seems unlikely, because of the well-preserved hexagonal bipyramid faces which many of the grains have. It is interesting that Watson and Watson (1912) report the presence of schistose quartz-albite porphyry with opalescent quartz phenocrysts at the Seminole mine a few miles to the north. The rocks in this part of Georgia are metamorphosed shales, tuffs, flows, and intrusive rocks; they are called the Little River series and are evidently the extension of the volcanic-slate belt of North Carolina (Crickmay, 1952; Stose and Smith, 1939).

The fine-grained character of quartz in the groundmass is very similar to the fine-grained quartz of probable hydrothermal replacement origin in the pyrophyllite deposits of North and South Carolina, suggesting that the fine-grained quartz at Graves Mountain was also formed by replacement. The irregular shapes and sizes of individual bodies and the innumerable thin crosscutting stringers of kyanite are suggestive of replacement origin also.

We have concluded, therefore, that the alumina-silica rock here was formed by hydrothermal action on silicic volcanic rock that contained quartz phenocrysts locally. It is possible that nearly all the primary constituents of the rock except silicon, aluminum, and titanium were leached by hot solfataric solutions, as described at Red Mountain, Colo., by Burbank (1950); some silicon and aluminum may have been introduced. Lazulite and pyrophyllite, and perhaps some rutile, were also transported by hydrothermal solutions, pyrophyllite being the last to form. Johnston (Prindle and others, 1935) has also concluded that the mineralization at Graves Mountain was of hydrothermal nature. Watson and Watson (1912) thought that the kyanite, lazulite, and rutile were formed by regional metamorphism, and that the pyrophyllite formed "from solution, as the final stage in gensis."

In 1940 an adit was driven on the southeastern slope of the mountain to get a large sample of fresh kyanite-quartz rock for flotation tests (Watkins, 1942). The sample contained about 30 percent kyanite, and the tests indicated that 4 tons of ore would yield about 1 ton of concentrates containing 96 to 97 percent kyanite.

Watkins has estimated that the central part of the mountain (1,500 ft long, 300 ft high, and 300 ft wide) contains about 10 million tons of rock that would yield about 2½ million tons of kyanite concentrates. His estimate of the average kyanite content is dubious, because it is based upon samples from only one place. Johnston (Prindle and others, 1935) estimated the kyanite content in different exposures to range from 1 to 30 percent. It is impossible to make a reliable visual estimate of the kyanite grade of the different bodies of kyanite-quartz rock on the mountain, but much of the rock contains between 10 and 30 percent kyanite; the massive rock on the main ridge seems to have more kyanite than the more schistose rock on the ends and slopes of the mountain. Although we believe that the structure of the deposit is considerably more irregular than the synclinal structure envisioned by Watkins, his tonnage estimate of about 10 million tons seems to be about the right order of magnitude for the 2 largest bodies in the central part of the mountain, provided they extend to depths of at least 200 to 300 feet beneath the surface with little change in size. Drilling would be necessary to determine the extent and grade of the bodies in depth.

Johnston (Prindle and others, 1935) describes the occurrence of kyanite-quartz rock at the Wingfield Plantation, about 11 miles southwest of Graves Mountain; we did not visit this locality. The outcrop is several hundred feet long, extending in a N. 60° E. direction; near its center is a large block, about 15 feet on a side, of kyanite-quartz rock. The rock contains hematite, indicating the presence of pyrite in the fresh rock; no rutile, lazulite, or pyrophyllite were found. No kyanite-quartz rock was found between this locality and Graves Mountain. According to Watson and Watson (1912), pyrophyllite was found in fractured quartz veins in quartzose rock by Veatch at a point on the Petersburg road, about 7½ miles east of Lincolnton and 13 miles east of Graves Mountain.

CLARKESVILLE DISTRICT, HABERSHAM AND RABUN COUNTIES

Kyanite occurs in Habersham and Rabun Counties in northeastern Georgia in a belt of graphitic mica schists that encircles a large dome of gneissic rocks. Most of the kyanite produced in Georgia has come from this area. As originally mapped by Prindle and others (1935), the schist belt was found to extend for a distance of about 30 miles part way around the flanks of the dome, in the shape of an elongate letter C open to the east. Recently

Teague and Furcron (1948) traced the kyanite schist nearly completely around the dome for a distance of about 45 miles; several miles of the belt extending through South Carolina are unmapped (fig. 56).

Most of the mining in the region has been done in the southern part of the schist belt within a few miles of Clarkesville, and along Raper Creek, 11 miles to the northwest. The mining operations and the more important kyanite schist, residual soil, and placer deposits are described in some detail by Prindle (Prindle and others, 1935) and R. W. Smith (1936). Mining was active from 1932 until 1949; total production is not recorded.

The Georgia-Carolina Minerals Corp. (later the Southern Mining and Milling Co.), under the supervision of Philip S. Hoyt, worked several deposits between 1932 and 1940. This company shipped a total of 1,100 tons of kyanite concentrates from 1932 through the end of 1935 from a residual soil deposit, 6 miles northwest of Clarkesville, and a placer deposit about 1 mile north of Clarkesville (Smith, R. W., 1936). In 1936 they began mining partly weathered kyanite schist at Alec Mountain and on Sutton Mill Creek, about 2½ miles northwest of Clarkesville. The different deposits were worked by small-scale hand-mining methods, and the kyanite recovered by simple milling processes. Kyanite was recovered from stream gravels by sluice boxes and hand jigs; material from the other deposits was disintegrated by means of a muller and the kyanite concentrated by a system of rotating and shaking screens, washboxes, and jigs (Smith, R. W., 1936; Boyd, 1940). In addition to kyanite, quartz and water-ground mica (for use as filler and roofing coating) were recovered from the weathered kyanite schist (Smith, R. W., 1936); flake graphite was later recovered by flotation, according to Furcron (1950).

In 1939 the A. P. Green Fire Brick Co. of Mexico, Mo., began mining in the area, and continued operations until 1949. They worked a placer deposit of 4 to 5 acres, on the wide flood plain of Raper Creek, about half a mile above its junction with Soque River; kyanite (fig. 23) and gravel were recovered from the deposit.

Thick platy crystals of blue-gray kyanite, commonly an inch or more long, half an inch wide, and a quarter of an inch thick, occur in coarse muscovite schist containing a small amount of graphite. Prindle and others (1935, p. 10) state:

> The thickness of the kyanite-bearing schists, so far as observed, ranges from 30 to 60 feet. The crystals are not uniformly distributed through the entire thickness. Beds a few inches thick and crowded with crystals alternate with beds of equal thickness where the crystals are more sparsely distributed, but in general the proportion of kyanite appears to be fairly persistent throughout.

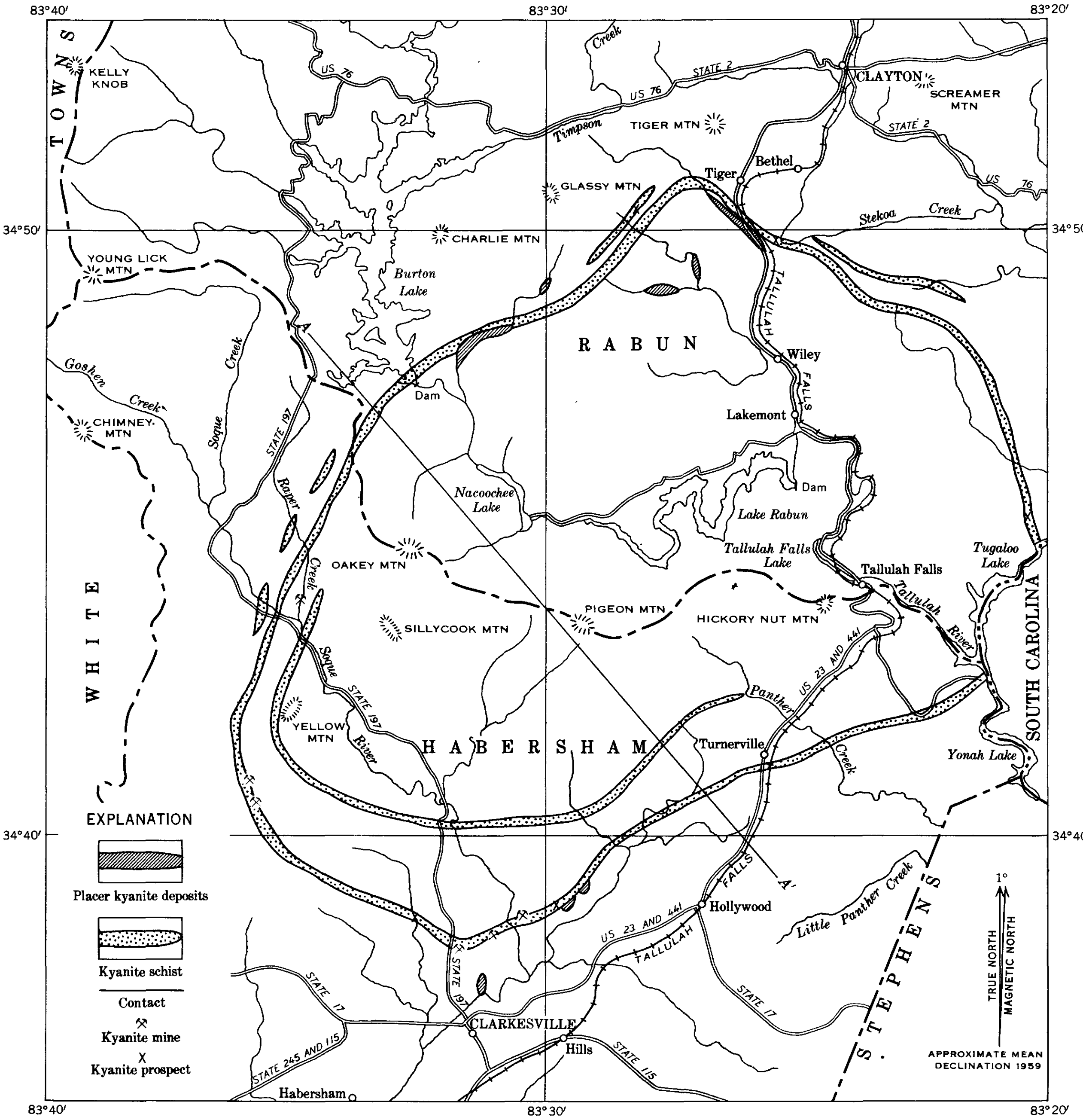
According to R. W. Smith (1936), the kyanite content of the schist ranges from 1 to 15 percent and has an average of about 6 to 8 percent at places favorable for mining. The kyanite schist dips outward from the dome, but it is very much contorted locally and the trends of both strike and dip may change as much as 90° within a distance of a few feet. Pegmatite is abundant in the kyanite schist at some places; it forms lenticular masses of quartz, feldspar, and muscovite that range in thickness from a few inches to 6 feet or more. Kyanite also occurs in some quartz veins and pods in the schist.

Layers of kyanite schist have also been found in the rocks above and below the main belt. Most of these beds appear to be short and discontinuous, except for one about 14 miles long underlying the main belt in the southern part of the dome (Teague and Furcron, 1948). The persistent distribution of the kyanite schists over a wide area indicate that they are stratigraphic units, and there can be little doubt that the aluminum was an original sedimentary constituent, as proposed by Prindle and others (1935).

Rocks associated with the main kyanite belt are feldspathic garnet-biotite, and hornblende gneisses. Rocks in the interior of the dome are mostly quartzite, graywacke, and gneiss; micaceous gneiss and schist with some hornblende gneiss lie above the main belt of kyanite schist (Teague and Furcron, 1948).

Coarse kyanite crystals occur in abundance in the soil along the schist belt; considerable limonite, quartz, and mica adhere to these crystals. Prindle and others (1935) state that kyanite concentrates recovered from a deposit of this type at Alex Mountain contained about 3 percent iron and 3 percent free silica.

Kyanite has also accumulated in significant amounts in stream gravels. Placer deposits of kyanite occur not only in the beds of present-day streams that cut the kyanite schist belt, but also in deposits of terrace gravel at higher elevations; Prindle and others (1935) describe several terrace deposits that lie 30 to 80 feet above present streams. These terrace deposits are evidently the remnants of gravels deposited by ancient streams; some of these older gravels may have been reworked and deposited in the alluvium of modern streams. Kya-



Base map and distribution of kyanite schist taken from map by K. H. Teague and A. S. Furcron (1948). Placer kyanite deposits taken from pl. 1, L. M. Prindle and others (1935)

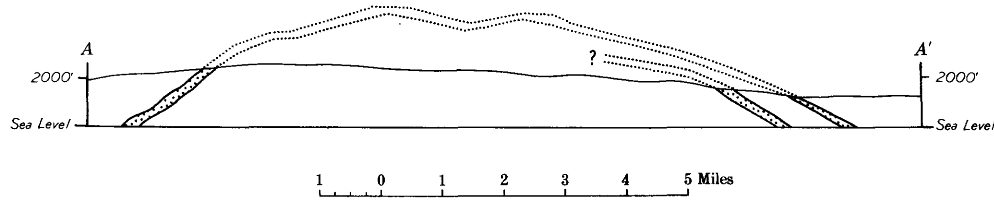


FIGURE 56.—Map and section showing distribution of kyanite schist and placer deposits in Habersham and Rabun Counties, Ga.

nite has been recovered from several placer deposits by mining operations; the crystals are somewhat rounded, and have been cleaned of adhering impurities by stream action (fig. 23).

TOWNS, UNION, AND FANNIN COUNTIES

Kyanite occurs in garnetiferous graphitic mica schists in extensive belts in Towns, Union, and Fannin Counties (LaForge and Phalen, 1913; Prindle and others, 1935). The kyanite is thoroughly replaced by muscovite and quartz at many localities. In the Mineral Bluff quadrangle, Fannin County, a thin band of quartz-kyanite schist, having a maximum thickness of 3 feet, has been traced by Hurst (1955, p. 34–35) for over 8 miles; silvery mica schists are associated with the quartz-kyanite schist. Kyanite also occurs as irregular masses of bladed crystals with vein quartz throughout the schist belt; several deposits of this type have been prospected or mined. About a carload of such material was mined from the Hogback Mountain area (Prindle and others, 1935). A kyanite-quartz deposit on Gumlog Mountain was prospected by the A. C. Spark Plug Co., and several tons of kyanite was found; the belt of kyanite schist in this area has a width of about half a mile (Prindle and others, 1935).

Kyanite and sillimanite occur together in graphitic quartz-muscovite schist near Brasstown Church, northern Towns County (Furcron and Teague, 1945), near the southwestern end of the Warne-Sylva sillimanite belt that extends from North Carolina. Sillimanite is the dominant mineral where the schist is intruded by numerous pegmatite dikes and stringers; kyanite is present where pegmatite is rare or absent. According to Hash and Van Horn (1951), sillimanite and kyanite occur together for a distance of about 3 miles between Winchester Creek and the North Carolina State line; kyanite is the only Al_2SiO_5 mineral in the schist to the southwest of Winchester Creek.

CHEROKEE, PICKENS, GILMER, AND DAWSON COUNTIES

Kyanite has been found in an area centering around Tate in north-central Georgia in three types of deposits: kyanite associated with staurolite in garnet-mica schists, kyanite in quartz veins, and massive kyanite consisting of rounded masses of interlocking kyanite crystals in schist and residual soil. The first two types are described by Bayley (1928) in his report on the Tate quadrangle; the third type is described by Furcron and Teague (1945).

The kyanite content of the staurolite-garnet-mica schist is variable, but kyanite is most abundant where the schist contains numerous quartz veins and stringers; kyanite is altered locally to muscovite. The principal localities of these kyanite-bearing schists are west of the Whitestone fault, a major overthrust that separates two groups of metamorphic rocks (Bayley, 1928, p. 122); kyanite is also found in some schists and gneisses east of the fault. In the area west of the fault, 1 belt of kyanite schists extends northeasterly for a distance of 5 to 6 miles between Keithsburg and Ball Ground, and another belt between 1½ and 2 miles long lies between Refuge Church and Harmony school; this latter belt was prospected at 1 point, according to Bayley.

Kyanite crystals are common in the quartz veins and adjacent country rock in this area of schist. A kyanite-quartz vein about 3½ miles west-southwest of Ball Ground was prospected. This vein was found to be 2 feet wide at 1 point and was traced for about 500 feet (Prindle and others, 1935); nearly a carload of the material was gathered for shipment from this prospect.

The massive kyanite, described by Furcron and Teague (1945), occurs as segregated masses of interlocking kyanite crystals found in the schist and residual soil. They are rounded or irregular in shape and as much as 800 pounds in weight; generally they are 50 pounds or less. The masses are fine grained, tough and heavy, and gray to green. They are made up of interlocking kyanite crystals that may be intergrown with muscovite (fig. 57) or corundum. Some contain a little quartz in fractures; garnet and black tourmaline are common on the surfaces. The masses seem most abundant where pegmatite and tourmaline-quartz veins occur. According to Furcron and Teague (1945), this type of kyanite is widespread in the schists and gneisses east of the Marble Hill overthrust fault. It is most common in a belt about 1 mile east of, and parallel to, the fault; garnetiferous biotite gneisses and schists occur in this area.

The massive kyanite of this area resembles massive kyanite from India (fig. 58), which has been imported to this country for many years for the manufacture of high-quality refractory articles. Refractory tests were made of samples of the Georgian massive kyanite by the Electrotechnical Laboratory of the U. S. Bureau of Mines, and it was found that the Georgian kyanite had many of the desirable qualities of the Indian kyanite (Furcron and Teague 1945). Although the Georgian kyanite ex-

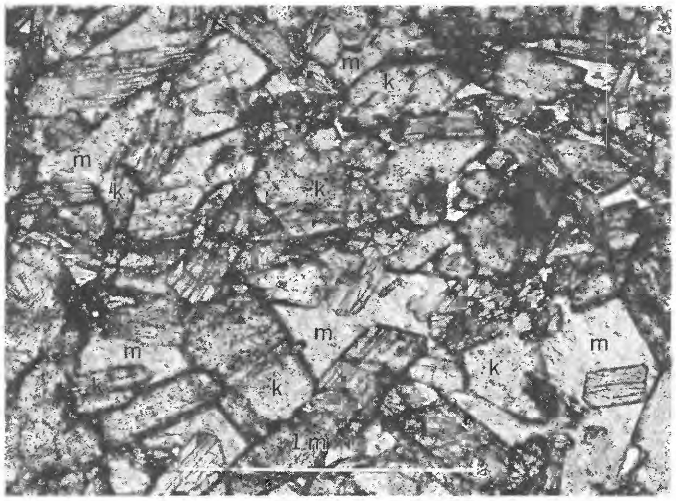


FIGURE 57.—Photomicrograph of massive kyanite from about 1 mile west of Long Swamp, Pickens County, Ga. Shows interlocking texture of kyanite crystals (k), with interstitial areas of fine-grained micaceous mineral, probably muscovite (m). Compare with massive kyanite from India (fig. 58). Plane-polarized light.

panded more than Indian kyanite when calcined, it produced a coarse grog, nearly 60 percent of which was coarser than 35-mesh. Standard bricks made from the calcined material were lighter and more porous than those made from Indian kyanite. One undesirable feature of the Georgian kyanite, however, is that much of it contains some fluxing materials, iron oxide and muscovite, that cannot be removed by hand cobbing, or even by scrubbing. Deposits of massive kyanite of minable size have not been found in this area.

TALBOT, UPSON, AND HARRIS COUNTIES

Kyanite occurs in the belt of Manchester schist overlying the Hollis quartzite at several places between Thomaston and Hamilton in west-central Georgia; the extent of the Manchester schist and associated Sparks schist is shown on the geologic map of Georgia (Stose and Smith, 1939).

The occurrences of kyanite in Talbot and Upson Counties are described by Crickmay (Prindle and others, 1935) and Clarke (1952). Small kyanite crystals are associated with quartz veinlets and pegmatite stringers in a zone of graphitic garnet-muscovite schist, about 30 feet thick and 200 feet above the base of the Manchester schist (Prindle and others, 1935). Crickmay reports that at places the kyanite seems more abundant in the soil than in the bedrock. A sample of soil from the Cherry property (3½ miles southwest of Thomaston), weighing 82 pounds, yielded 12 ounces of kyanite by washing, equivalent to a little less than 1 percent kyanite by weight (Prindle and others, 1935). Kyanite, staurolite, and garnet are found in the soil here over an area about 1,400 feet long and 50 to 200 feet wide (Ingram, 1950). A sample of kyanite schist taken from the west bank of the Flint River, 1½ miles below Pasley Shoals, was found by Clarke (1952) to contain about 8 percent kyanite. He also found that feldspathic gneisses surrounding a large granite body near Thomaston commonly contains 1 to 3 percent kyanite; 1 specimen contained 1 percent kyanite and 2 percent sillimanite.

In Harris County near the western end of the belt of Manchester schist, kyanite was found in the alluvium of Mountain Creek by D. W. Caldwell (written communication, 1952) during the Geological Survey's study of the distribution of monazite in Southeastern placer deposits. Samples of alluvium from several localities contained about ½ to 1 percent kyanite in particles less than one-quarter of an inch long. Mountain Creek drains an area of Manchester schist here, which is presumed to be the source of the kyanite. The Hollis quartzite extends westward from here into Alabama (Hewett and Crickmay, 1937), and perhaps the overlying Manchester schist does also; there seems to be no published record on the occurrence of kyanite schist along the extension of this belt in Alabama.

OTHER LOCALITIES

On the T. F. Carter property, Fulton County, about 1½ miles southwest of Dunwoody, kyanite occurs in kyanite-garnet-mica schist, and is found in the soil in a belt 320 feet wide and at least 600 feet long (Crickmay, *in* Prindle and others, 1935). The locality had not been thoroughly prospected

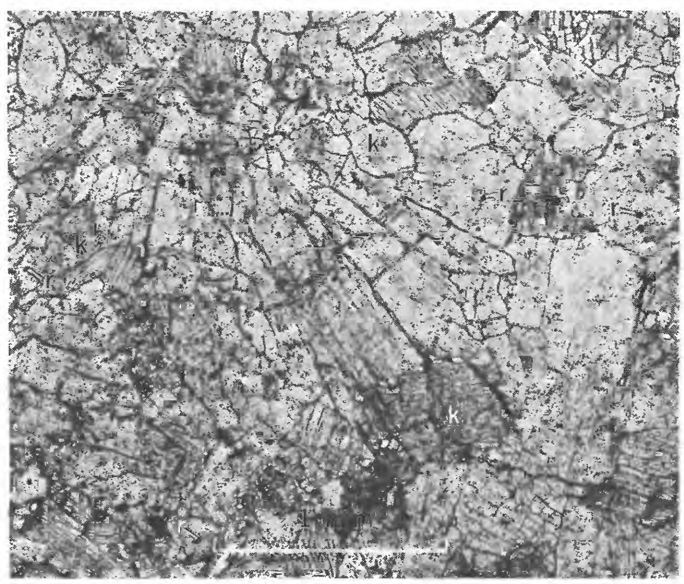


FIGURE 58.—Photomicrograph of massive kyanite from India. Shows interlocking texture of kyanite crystals (k), with abundant inclusions of tiny rutile grains (r). Plane-polarized light.

when seen by Crickmay. Kyanite and garnet are abundant in some of the wall rock at the Reeds Mountain pyrite deposit, in Carroll and Haralson Counties, according to Shearer and Hull (1918). At the Battle Branch gold mine, Lumpkin County, kyanite is found at the bottom of two ore shoots and in the wall rock (Pardee and Park, 1948). Kyanite and sillimanite-bearing schists are minor rock types in the Stone Mountain-Lithonia district (Herrmann, 1954).

ALABAMA

Small deposits of bladed kyanite in quartz veins and in pegmatites occur in the metamorphic belt of east-central Alabama. On Turkey Heaven Mountain in Cleburne County, a locality previously noted by Bowles (1939), kyanite occurs in small quartz lenses in locally contorted areas of fine-grained graphitic mica schist. Coarse blue kyanite occurs with quartz at the Jim Flemming pegmatite mine in sec. 24, T. 17 S., R. 10 E., Cleburne County (Heinrich and Olson, 1953), and was also found by us on the John Creed property about half a mile to the north. Float of coarse kyanite occurs at the Friendship No. 1 pegmatite mine, Randolph County, and the Smith No. 1 pegmatite mine, Clay County (Heinrich and Olson, 1953). Kyanite float has also been found in Coosa, Tallapoosa, and Chilton Counties, according to Bowles (1939).

SILLIMANITE DEPOSITS

VIRGINIA

Sillimanite has been found as a minor constituent of metamorphic rocks at a few places in Virginia; more occurrences will doubtless be discovered. In the northern part of the Willis Mountain area, Buckingham County, small amounts of sillimanite are associated with kyanite in quartzite and quartz-muscovite schist, and in coarse amphibole rock at several localities. Taber (1913) reports the occurrence of sillimanite with kyanite in garnetiferous quartz rock farther north in Buckingham County near New Canton and in Goochland County near Lantana. Sillimanite occurs in minor amounts in some pegmatites in the Anna River area of Spotsylvania, Caroline, Hanover, and Louisa Counties, and in Goochland and Powhatan Counties (Griffitts and others, 1953); it has also been found with graphite in garnetiferous schist in the pegmatite district of Amelia County (Lemke and others, 1952).

NORTH CAROLINA

The principal known localities of sillimanite in North Carolina consist of two extensive belts of sillimanite schist—the Cliffside-Elkin belt near the west edge of the Piedmont and the Warne-Sylva belt in the southwestern Blue Ridge. The two belts of sillimanite schist have been investigated jointly by the North Carolina Division of Mineral Resources and the Tennessee Valley Authority to determine their potential economic importance (Hunter and White, 1946; Hash and Van Horn, 1951). Sillimanite schists in the Shelby quadrangle in the southern part of the Cliffside-Elkin belt have been mapped by Yates, Overstreet, and Griffitts (written communication, 1954) in their monazite studies for the Geological Survey. Sillimanite schist and small deposits of sillimanite quartzite in the Kings Mountain district of Gaston and Lincoln Counties were discovered during the present study.

The Cliffside-Elkin belt of sillimanite schist trends northeasterly for over 80 miles from the South Carolina line to near Elkin, N. C.; it is the northern part of the sillimanite schist belt that extends through the Piedmont of Georgia, South Carolina, and North Carolina. Sillimanite schist is abundant within this zone; it also occurs outside the zone, but in deposits that seem to have less potential importance. The extent of the zone of sillimanite schist between the Catawba River, N.C., and the Savannah River, S.C., has been outlined by Overstreet and Griffitts (1955) on the basis of heavy mineral content of hundreds of samples of stream alluvium.

In the Cliffside-Elkin belt, sillimanite is generally present in biotite-muscovite-quartz schist. It may occur as fibrous crystals uniformly distributed through the rock, it may be segregated in layers, or it may occur as lenticular aggregates that range from small platy lenses less than an inch in length to large rounded nodules over a foot in diameter and weighing several hundred pounds. Garnet, staurolite, chlorite, and graphite are present in much of the rock, and rutile, ilmenite, hematite, and zircon are widespread accessory minerals; tourmaline, barite, chromite, and pyrite are among the heavy accessory minerals at some places (Hash and Van Horn, 1951). Partial alteration of sillimanite to sericite is very common, and at some localities this alteration is nearly complete. Quartz veins and small pegmatite lenses are abundant, and large granitic bodies are widespread in the belt.

Hunter and White (1946) and also Hash and Van Horn (1951) concluded that the sillimanite schist occurs in a very broad long shear zone. Hash and Van Horn (1951, p. 4-5) describe the shearing effects as follows:

> Individual shear zones vary up to several hundred feet in thickness and are readily evident by their fragmentary appearance. Evidence of shearing is present in many orders of magnitude, varying from minute intragranular shearing, seen only with the microscope, to large persistent fault planes which may be traced for considerable distances along the outcrop. The commonest evidence of shearing is found in small fragments which have been dragged into somewhat sigmoidal shapes.

These investigators believe that the sheared nature of the rock facilitated the thorough permeation of the schist by pegmatite, which was important in the formation of sillimanite. Hunter and White (1946, p. 6) state that "sillimanite * * * had its origin in mobile solutions emanating from these small pegmatites."

Hash and Van Horn (1951, p. 3) thought that "The excess of alumina necessary for the formation of sillimanite was derived presumably from the schist and concentrated by the pegmatites under pressure."

Sillimanite schist is distributed so widely in the broad belt extending through the Piedmont of North Carolina, South Carolina, and eastern Georgia, that it seems very improbable that its origin is related to shear zones. According to Overstreet and Griffitts (1955), the sillimanite schist belt is bordered on the east and west by lower grade rocks of the staurolite-kyanite subfacies. It thus resembles the areas of sillimanite schist and gneiss that are characteristic of very high grade metamorphism in many regions. Overstreet and Griffitts (1955) believe that sillimanite was formed by reaction between mica and quartz rather than by hydrothermal alteration. They think that the potash released from this reaction may have combined with potash-bearing fluids of magmatic origin to form the pegmatite bodies. By their interpretation, the formation of sillimanite would have contributed to the formation of pegmatite, instead of the reverse process as proposed by Hunter and White (1946) and Hash and Van Horn (1951). It is possible also that the aluminum for sillimanite was mostly derived directly from argillaceous material in alumina-rich sediments rather than from the breakdown of mica.

In the Shelby quadrangle, the only part of this belt in North Carolina in which the geology has been mapped in detail, sillimanite schist occurs in long curving bodies, as much as several miles wide, in association with large areas of biotite schist (Yates, Overstreet, and Griffitts, written communication, 1954). The foliation in both types of schist follows curving and irregular trends, and it is evident that the schists have been very highly folded and probably also faulted. Sill-like bodies of granitic rock, known as the Toluca quartz monzonite, intrude both the sillimanite and biotite schists. The sillimanite schist commonly contains between 5 and 20 percent sillimanite and underlies 30 percent of the quadrangle, or about 73 square miles. The distribution pattern of the sillimanite schist in the Shelby quadrangle certainly does not suggest its localization in shear zones, but Hunter and White (1946) thought that the shear zones had been deformed by later folding.

Hash and Van Horn (1951) examined the deposits of sillimanite schist in this belt that seemed to have most economic promise, made geologic maps of several localities, and also took samples for separation of the heavy minerals and determination of content and quality of the sillimanite. Beneficiation tests were made of samples from the more promising deposits. It was found necessary to grind to minus 100-mesh to liberate the sillimanite in most samples; it was difficult, or, in some cases, impossible, to obtain an acceptable sillimanite flotation concentrate where the sillimanite was strongly sericitized. The more important results of their study are summarized below.

In Cleveland County sillimanite schist was investigated in the vicinity of Polkville, Wards Creek, and Casar; these deposits are mainly in the Shelby quadrangle. The Wards Creek deposit seemed particularly promising because the sillimanite there is very little altered to sericite.

One of the best exposures of sillimanite schist known in the belt is at Smith Cliff, Burke County, where nearly continuous rock outcrops are found for a distance of about 700 feet along the face of a steep cliff, about 300 feet high, above a sharp bend in Henry Fork Creek. Sillimanite occurs in quartz-biotite-muscovite schist, along with small amounts of tourmaline, graphite, garnet, feldspar, and pyrite. Sillimanite is present as very small crystals disseminated through the schist and also as small platy nodules as much as 2 inches long. The schist is intruded by many granite bodies, some of which are 25 feet wide and 100 feet long, and by countless small pegmatite bodies up to 3 feet wide and several feet long; pegmatite makes up from 20 to 30 percent of the rock material in places. Most of the samples taken from here contain between 5 and 7 percent sillimanite; the sillimanite is partially altered to sericite, and, as a result, the beneficiation tests yield rather low recoveries.

In Caldwell County sillimanite schist deposits near Saw Mills, at Cages Mountain, and in the vicinity of Dudley Shoals were investigated by Hash and Van Horn. Sillimanite nodules and schist float are found along a ridge near Saw Mills; a sample of the schist float contains 9.4 percent sillimanite. At Cages Mountain sillimanite schist is well exposed in a road cut on the highway between Rutherford College and Whitnel, and forms abundant float on the long east-trending ridge. Samples taken from the road cut for a distance of nearly 70 feet across the strike contain between 10.2 and 14.5 percent heavy minerals, mostly sillimanite. The sillimanite here is very fine grained and intergrown with biotite and muscovite (fig. 21). In beneficiation tests a product with suitable Al_2O_3 content could be obtained only by very fine grinding and by accepting a low recovery of the total sillimanite content. In the Dudley Shoals area three deposits of sillimanite were examined; granite is widespread here. Outcrops are scarce but float of sillimanite schist and sillimanite crystals is abundant. At 2 localities coarse crystals of sillimanite occur in nodular aggregates, some of which are 2 to 3 feet in diameter and weigh several hundred pounds; a sample of this nodular sillimanite contains 59.3 percent Al_2O_3 and 2.7 percent Fe_2O_3 without beneficiation. Samples of schist float from the Dudley Shoals deposit 1 contained from 16.5 to 31.8 percent sillimanite; sericitic alteration of the sillimanite appears to be less here than at any other deposit.

Several bands of sillimanite schist, 50 to 100 feet wide, occur at the Ellendale School area, Alexander County; microscopic examination of the material shows that a large part of the sillimanite is altered to sericite. At the Fox's Orchard deposit in Iredell County, sillimanite nodules as large as 2 inches in diameter occur in schist zones about 15 feet wide. Beneficiation tests indicated that a commercial product could not be made from this material because of strong sericitic alteration of the sillimanite and heavy iron staining. Garnetiferous schist with very fine grained sillimanite also occurs in this area, but it does not seem to be of commercial value. Sillimanite schist, in bands a few feet to several hundred feet wide, were examined by Hash and Van Horn at various other places in the Wilkesboro-Taylorsville area at the northern end of the belt. Samples from 2 deposits contain 11 to 12 percent sillimanite, but others are under 10 percent. They found that sericitic alteration of the sillimanite had been extensive in this area.

The other major belt of sillimanite schist is in the Blue Ridge of the southwestern part of the State, and extends southwesterly from near Sylva for about 50 miles through Jackson, Macon, and Clay Counties to the Georgia line (Hash and Van Horn, 1951); sillimanite schists are also found for several miles farther southwest in Towns County, Ga. (Furcron and Teague, 1945). Sillimanite occurs in graphitic garnet-quartz-muscovite schist that is intruded by many small pegmatite lenses. Subordinate amounts of kyanite accompany sillimanite at most of the localities sampled by Hash and Van Horn in this belt. Biotite, epidote, and staurolite are present in some schist; and zircon, rutile, hematite, and ilmenite are the most common accessory minerals.

Exposures of sillimanite schist are numerous in this zone because of the mountainous terrain. Hash and Van Horn (1951) were able to trace the zone with layers of sillimanite schist up to a few hundred feet wide, almost continuously from Davy Mountain near Warne to Sylva, a distance of about 45 miles; the layers of sillimanite schist are shown in their report on topographic maps at a scale of 1:24,000. Some of the results of their sampling are summarized below; they indicate the range in the content and quality of sillimanite.

Locality	Width of sample (feet)	Sillimanite	
		Percent	Nature
Hyatt Mill Creek	(?)	4.2–6.0	Sericitized.
Downing Creek area [1]	(?)	5.4–9.9	Do.
Sap Sucker-Cold Branch area	40	2.5	Not stated.
	20	7	Do.
Saldeer Gap area	40	8 ±	Sericitized.
	30–40	15.3	Do.
Etna-Bradley Creek	[2] 45–65	[3] 7.0–13.5	Do.
Rickman Creek	35	5.7	Do.
	30	2.6	Do.
Matlock Creek	15	9.7	Do.
Cowee Church	60	13.7	Clear.
	60	13.2	Do.
Leatherman	50	19.5	Little sericitized.
Greens Creek School	25	17.4	Do.
Rivierview Church	20–60	6.4–19.6	Do.
Sylva	30	11.3	Do.

[1] Rounded aggregates of coarse sillimanite in masses weighing as much as 300 lb. are found in talus along Downing Creek; small lots of this material have been collected and sold as kyanite.
[2] 5 channel samples.
[3] Average, 9.7.

Sillimanite schist was also examined by Hash and Van Horn northeast of Sylva at several localities in Jackson, Haywood, and Buncombe Counties and between Asheville and Mount Mitchell. A sample of sillimanite schist taken from the Grassy Ridge mica mine, Jackson County (about 9 miles northeast of Sylva) contains 5 percent of unsericitized sillimanite; when ground to minus 200-mesh it yielded a flotation concentrate that contains 62.6 percent Al_2O_3 and 2.0 percent Fe_2O_3, with recovery of 80 percent of the sillimanite.

In Gaston and Lincoln Counties in the Kings Mountain district, thin layers and lenses of sillimanite quartzite and schist occur in zones adjacent to the east and west sides of the Yorkville quartz monzonite body; long narrow inclusions of sillimanite schist, sillimanite gneiss, and microcline-sillimanite-corundum gneiss are present within the quartz monzonite near its western contact (pl. 7). These deposits are described in the section on the Kings Mountain district (p. 90). Some of the sillimanite-bearing belts in the Kings Mountain quadrangle had previously been mapped as kyanite quartzite by Keith and Sterrett (1931).

SOUTH CAROLINA

The Piedmont sillimanite schist belt extends northeasterly across South Carolina through Anderson, Greenville, Spartanburg, Laurens, and Cherokee Counties (Smith, L. L., 1945; Hudson, 1946; Teague, 1950; Overstreet and Griffitts, 1955). Sillimanite occurs in biotite-muscovite-quartz schists that generally contain a little graphite; garnet and tourmaline are also present at some localities. The sillimanite schists are generally intruded by innumerable small lenses and thin stringers of pegmatite and granite. Large bodies of biotite granite are widespread, and L. L. Smith (1945) concluded that much of the sillimanite schist occurs as roof pendants in the granite, and that the sillimanite schists were formed by contact metamorphism of aluminous sedimentary rocks.

The sillimanite schist belt in South Carolina has been investigated by the U.S. Bureau of Mines, the South Carolina Geological Survey, and the South Carolina Research, Planning and Development Board in an effort to discover deposits of potential economic importance. Overstreet and Griffitts (1955) have outlined the area of sillimanitic rocks in the State. One of the most promising areas is in Pelzer and vicinity in Anderson and Greenville Counties, where 9 bodies of schist were found, ranging from 30 to 240 feet in surface width (Hudson, 1946). A sample of sillimanite schist weighing 7,500 pounds and containing 17 percent sillimanite was taken by the Bureau of Mines from an outcrop, 20 feet in width, on the Beam property near Pelzer. Flotation tests of the sample yielded satisfactory sillimanite concentrates from which test refractory bricks of high quality were made (Rampacek, Clemmons, and Clemmer, 1945). Samples from 3 diamond-drill holes drilled to maximum vertical depths of about 100 feet by the Bureau of Mines indicated considerable granite with thin layers of sillimanite schist; samples from 1 drill hole contain between 6 and 10 percent sillimanite, and those from another hole have about 3½ percent. Samples from 3 holes drilled to a maximum vertical depth of 65 feet on the Pearson and Scott properties, three-quarters of a mile northeast of the Beam property, also contain a lower sillimanite content than indicated by surface exposures and float; the highest sillimanite content of the drill samples is about 6 percent.

The Alexander and Barber properties (Hickman, 1947) and the Gideon property (Dosh, 1950) in southeastern Spartanburg County were also explored by diamond drilling by the U.S. Bureau of Mines. Two drill holes at the Alexander property penetrated mostly granite at shallow depths; samples from 1 hole contain no sillimanite and from the other between 1 and 1½ percent. The best samples taken from 5 drill holes at the Barber property contain about 5 percent sillimanite. At the Gideon deposit, 1½ miles southwest of Cross Anchor on South Carolina Highway 92, high-grade coarse sillimanite-biotite-quartz schist (fig. 22) is found in roadside outcrops and as float in the fields; 6 shallow drill holes here penetrated granite and very little sillimanite schist.

Other areas examined by the Bureau of Mines are in the vicinity of Greer, Taylors, and Paris Mountain, Greenville County (Hudson, 1946). Two samples of sillimanite schist taken near Greer contain 12 to 18 percent sillimanite. In beneficiation tests on these samples, 65 percent of the total sillimanite in 1 sample was recovered and 76 percent in the other; the product was much finer grained and had more iron than the material from near Pelzer. Ten bodies of sillimanite schist as much as 700 feet wide were found in the Taylors area; 3 samples contain from 6 to 8 percent sillimanite. The schist at Paris Mountain on the west side of the belt is cut by many granite bodies and has a low sillimanite content.

Additional occurrences of sillimanite schist were found in 1949 by J. K. Yates and S. D. Heron[12] at Buck and Island Creeks in northeastern Spartanburg County, the Thicketty Mountain area in northwestern Cherokee County, the Tyger River and Enoree areas in southeastern Spartanburg County,

[12] Investigation carried out by the South Carolina Research, Planning and Development Board. The unpublished reports and maps of Yates and Heron were made available to the writers by B. F. Buie of the Board.

and the Greer area in Greenville County. These occurrences of sillimanite schist appear to be very similar to those investigated by the Bureau of Mines.

Sillimanite has also been found at the Ross tin mine, 1½ miles northeast of Gaffney, Cherokee County (Keith and Sterrett, 1931, p. 11), and in thin layers of quartzite on the Ryan-Purcley properties in York County in the Kings Mountain district (pl. 7).

GEORGIA

The principal occurrences of sillimanite in Georgia are in the southwestern extension of the Piedmont sillimanite schist belt. Within this belt, sillimannite schist is most abundant in an area about 23 miles long and 1 to 2 miles wide in Madison, Elbert, and Hart Counties. Hudson (1946, p. 6) reports 126 localities of sillimanite schist in these 3 counties in comparison with a total of 21 localities discovered in 9 counties farther southwest. The occurrences of sillimanite schist here are similar to those to the northeast in the Carolinas. Sillimanite is most abundant in garnetiferous biotite-muscovite-quartz schist that is several hundred feet wide; tourmaline, graphite, and magnetite are accessory minerals. The richest sillimanite schist, containing coarse bundles of crystals up to 2 inches long and a quarter of an inch thick, extends over a distance of about 15 miles. Float fragments of massive muscovite containing corundum were found by Furcron and Teague at a point about 2 miles southeast of Bowman. The schist is cut by abundant small pegmatite and granite bodies, and large areas of granite lie on either side of the zone (Furcron and Teague, 1945). The geology of Hart County has recently been studied by Grant (1958). Sillimanite and kyanite are dominant heavy minerals of some schist saprolite in the Athens area, according to Hurst (1953).

Some of the deposits of sillimanite schist in this belt were investigated in 1945 by the U.S. Bureau of Mines and the A. P. Green Fire Brick Co. (Hudson, 1946). Two areas in the belt were prospected and sampled, the Norman area about 2½ miles southeast of Bowman and the A. P. Green area about 5 miles northeast of Bowman. In the Norman area, float of sillimanite schist is found over a length of about half a mile and a maximum width of about 600 feet. Samples from 5 diamond-drill holes drilled by the Bureau of Mines indicated a body of hard sillimanite schist about 50 feet wide; the best values were 7.8 percent sillimanite over an interval of 35 feet in 1 drill hole. An auger hole put down by the A. P. Green Fire Brick Co. in the Norman area had 3.07 percent recoverable sillimanite to a depth of 40 feet.

In the A. P. Green area, bodies of hard sillimanite schist 10 to 15 feet wide and as much as 1,000 feet long occur in a zone 1 mile long and half a mile wide. Two holes that were drilled on the Cheek farm by the Bureau cut schist having a sillimanite content that ranged between 0 and 22.3 percent. A sample weighing 8,700 pounds taken from here by the Bureau contains 17 percent of recoverable sillimanite. Hudson (1946, p. 16, 18–29) quotes the following results of 3 auger holes drilled by the A. P. Green Fire Brick Co. here:

Auger hole	*Recoverable sillimanite (percent)*	*Sample length (feet)*
38	4.20	40
49	9.86	38
70	8.26	40

In 1945, the Georgia Department of Mines, Mining and Geology and the Tennessee Valley Authority jointly explored the J. I. Jenkins property in this same area by means of nine pits and trenches (Teague, 1950). Coarse sillimanite-mica schist cut by numerous small pegmatite lenses was exposed.

Microscopic examination shows the schist to be composed mainly of quartz, dark-brown biotite, sillimanite (closely associated with the biotite), and some muscovite; irregular opaque inclusions apparently are graphite. The weathered rock is heavily stained with limonite.

Teague (1950) estimated that an area three-quarters of an acre in extent on the Jenkins property would have about 610,000 tons of material containing 10 percent sillimanite above local drainage level and about 8,500 tons per vertical foot below drainage level; he estimates reserves of over 4,000,000 tons of such material for this and nearby properties. The sillimanite content of the schist in this belt had originally been assumed to be about 15 percent by Furcron and Teague (1945), but the results, just summarized, of the prospecting and sampling at several localities indicate that the average sillimanite content is probably about 10 percent or less. The deposits of sillimanite schist in Elbert and Hart Counties are the most promising known in the State.

Sillimanite has also been discovered in two areas in the Blue Ridge. The Warne-Sylva belt described by Hash and Van Horn (1951) extends southwest from North Carolina for several miles into Towns County, Ga.; a selected sample taken from the road cut at Brasstown Church contains about 4 percent sillimanite (Furcron and Teague, 1945). The other sillimanite locality is in the area of massive kyanite deposits near Old Johnstown, Dawson County, where small flattened pebblelike masses of fine-grained fibrous sillimanite and quartz occur in coarse biotite gneiss; the sillimanite content of one of these small lenses was determined by microscopic examination to be about 25 percent (Furcron and Teague, 1945).

ALABAMA

Sillimanite schist was found in Randolph and Clay Counties, Ala., by W. T. McDaniel, Jr., of the Tennessee Valley Authority, in 1944, according to Teague (1950); the extent and quality of these deposits have not been investigated.

ANDALUSITE DEPOSITS

VIRGINIA

Andalusite has been found in Fairfax County by Charles Milton (written communication, 1953), of the Geological Survey. It occurs with quartz in quartz-mica schist at the edge of bodies of greenstone; usually the andalusite is completely sericitized. Andalusite, kyanite, and coarse muscovite occur in quartz in andalusite schist near Difficult Run, about 1.6 miles north-northwest of Oakton. Andalusite schist is also found in the old railroad cut just south of Virginia Highway 211, about 1¼ miles east of Sisson. Andalusite is reported to occur with kyanite and corundum on a knob of Bull Mountain near Stuart in Patrick County (Genth, 1890); we were not able to find this locality.

NORTH CAROLINA

Andalusite occurs in mica schist and in sillimanite quartzite in the Kings Mountain district, and is present in some abundance in several of the North Carolina pyrophyllite deposits; it was first recorded from the Gerhardt (Staley) pyrophyllite mine by Burgess (1936). The pyrophyllite deposits are lenticular bodies that seem to have been formed by hydrothermal replacement in silicified zones in silicic volcanic rocks (Stuckey, 1928). The deposits all occur in the Piedmont belt of volcanic rocks and slates (pl. 1). The occurrence of andalusite and lesser amounts of other high-alumina minerals (diaspore, topaz, and kyanite) in some of these pyrophyllite deposits has been described by Broadhurst and Councill (1953). They point out that in some deposits the footwall is nearly pure quartz rock and the hanging wall is sericite schist. The deposits were examined briefly by us, but not mapped, following the discovery of andalusite by the North Carolina State geologists. The descriptions given below are taken mainly from our own field observations and petrographic studies.

BOWLINGS MOUNTAIN, GRANVILLE COUNTY

A pyrophyllite deposit about 1,000 feet long trends N. 15° E. along the ridge of Bowlings Mountain, about 3 miles northwest of Stem. Massive and crystalline pyrophyllite occur in very fine grained siliceous zones in sericite schist. Tough white granular rock containing coarse-grained andalusite, quartz, and pyrophyllite is present in parts of the deposit (fig. 17). Light-gray to tan dense chertlike topaz, identical in appearance with the dense topaz from the Brewer deposit, South Carolina, is abundant as float to the east of the northern end of the deposit, and also occurs as stringers a few inches thick in pyrophyllite in the southernmost opencut. The deposit was prospected by a shallow opencut shortly before the time of the pyrophyllite investigation by Stuckey (1928, p. 57); it was then known as the Harris prospect. The Carolina Pyrophyllite Co. began work here about 1949 or 1950. The rock is being mined from 2 opencuts and trucked to the grinding plant at Staley, about 80 miles to the southwest.

Another deposit of pyrophyllite occurs on a prominent ridge rising nearly 200 feet above the surrounding countryside, about 14 miles northeast of the Bowlings Mountain deposit, 9 miles northwest of Oxford, and about 1½ miles east of North Carolina Highway 96. Float and low outcrops of dense siliceous rock are abundant for about three-quarters of a mile along the ridge. Chloritoid occurs in some rock; disseminated hematite and magnetite are also present. Blocks of massive pyrophyllite, 1 to 2 feet long, are distributed along a distance of 600 to 700 feet at the north end of the ridge. Other aluminous minerals have not been discovered.

HILLSBORO, ORANGE COUNTY

A deposit of pyrophyllite on a prominent ridge just south of the town of Hillsboro, Orange County, was prospected by the North State Pyrophyllite Co. in the fall of 1952. Opencut mining was started here a few years later. The andalusite-pyrophyllite-quartz ore is shipped to the company's plant at Pomona, N.C. (near Greensboro), where it is blended with other materials and used to manufacture firebrick and brickkiln furniture.

A body of andalusite-pyrophyllite-quartz rock over 1,200 feet long and 50 to 150 feet wide has been exposed by stripping and trenching. The deposit strikes about N. 50° E., and dips 60° to 80° NW. It has a footwall of dense siliceous rock that forms the crest of the ridge and a hanging wall of sericite schist. Coarse grains of light-gray to greenish-blue andalusite occur with pyrophyllite and very fine grained quartz (fig. 19); andalusite seems considerably more abundant than pyrophyllite in much of the deposit. Nearly massive coarse tan andalusite occurs in aggregates near the northern end of the body, with masses of radiating pyrophyllite, and a little diaspore and topaz. The ridge continues for a quarter of a mile or more southwest of the southern end of the deposit just described; float and rounded outcrops of siliceous rock are abundant, but andalusite and pyrophyllite are not evident.

SNOW CAMP, ALAMANCE COUNTY

The Snow Camp (Holman's Mill) deposit is a lenticular body of massive pyrophyllite and fine-grained quartz about 350 feet long and 250 feet wide, lying about 3½ miles southeast of Snow Camp. Rounded knobs of fine-grained siliceous rock crop out just south of the deposit. Coarse-grained andalusite was found in a zone several feet wide in the northern part of the deposit, but it does not seem to be very abundant; no other high-alumina minerals were identified in the few samples examined. The deposit is mined by the North State Pyrophyllite Co. in an opencut about 200 feet long, 150 feet wide, and 40 feet deep. The pyrophyllite rock is trucked to the company's plant at Pomona, N.C.

STALEY, RANDOLPH COUNTY

The Staley (Gerhardt) deposit, about 5 miles west of Staley, is a lenticular body about 350 feet long and 100 to 200 feet wide. A zone of massive pyrophyllite between 10 and 40 feet wide lies in fine-grained quartz-pyrophyllite rock. According to Stuckey (1928, p. 55), the hanging wall of the deposit is volcanic ash and the footwall is medium-textured volcanic tuff. The deposit dips 60° to 70° NW. Burgess (1936) first noted the occurrence of andalusite, kyanite, and topaz here; they all seem to occur in very small amounts. Andalusite is possibly the most abundant, and it forms local aggregates of crystals several inches long that are intergrown with radiating pyrophyllite. Fine-grained diaspore, rutile, and scattered small grains of lazulite are also present.

The Staley deposit is worked by the Carolina Pyrophyllite Co. in a pit over 100 feet deep; the rock is ground at the company's plant in Staley, and the product used for the manufacture of tiles and other ceramic ware.

OTHER LOCALITIES

Broadhurst (1955, p. 49) states that "andalusite and diaspore have been reported from the Comer-Aumen deposit in northeastern Montgomery County and the Hinshaw property in western Moore County." We have no other information about these deposits.

SOUTH CAROLINA

In the volcanic-slate belt in South Carolina, andalusite and other high-alumina minerals occur in some abundance in two quartzose deposits—the Brewer gold mine and Boles Mountain—and are known in minor amounts at several other localities; these occurrences are described below. Andalusite is present in very small quantities in schist adjacent to kyanite quartzite at Henry Knob, York County p. 85).

BREWER DEPOSIT, CHESTERFIELD COUNTY

Andalusite, topaz, kyanite, and pyrophyllite occur together at the old Brewer gold mine, about 1½ miles west of Jefferson, S.C. Gold was discovered here in 1828. About $450,000 worth of gold was recovered from placer and lode workings until cessation of gold mining in the late nineties (Pardee and Park, 1948, p. 106). Some gold mining was being done in 1935. The United Feldspar and Minerals Corp. began exploration for topaz in 1939, and conducted tests on the utilization of topaz in making mullite refractories. Massive topaz was produced from 1941 to 1948, being recovered partly from residual accumulations in the soil and partly from bedrock. The recorded production of topaz for 3 of these years amounts to 3,577 tons; the unrecorded production was probably several thousand tons.

The deposit was visited only briefly by us; the following information is taken mainly from other workers. The topaz here is an unusual variety, being extremely fine grained and massive, mottled bluish gray, and very similar in appearance to chert. Its specific gravity, however, is about 3.5 in contrast to 2.6 for chert. This mineral was not recognized as topaz until 1935, when the Brewer gold deposit was being studied by J. T. Pardee and C. F. Park, Jr., of the Geological Survey (Pardee, and others, 1937; Pardee and Park, 1948); the occurrence of topaz here was later investigated more fully by Fries (1942). Andalusite and kyanite have since been discovered in the deposit also.

The Brewer lode is an irregular poorly defined mass of very fine grained quartz between 200 and 300 feet wide and over 1,000 feet long. It was apparently formed by the silicification of quartz-sericite schist that was originally rhyolite tuff and breccia (Pardee and Park, 1948). The unweathered silicified rock contains finely disseminated pyrite in amounts ranging between 2 and 5 percent; the gold is presumably contained in the pyrite. The topaz and associated aluminous minerals occur in a zone extending northwest from the main Brewer lode. The main deposit of topaz consists of irregular veins and masses of dense topaz replacing silicified rock in a zone about 100 feet wide and 200 feet long (Fries, 1942). Other outcrops of topaz-bearing rock are scattered to the northwest. Kyanite and pyrophyllite float are found southeast of the main lode, along the east-trending valley into which the drainage tunnel from the Brewer pit opens.

Topaz is well exposed along the crest of the ridge and in an opencut from which topaz has been mined. According to Fries (1942), the topaz bodies are very irregular in size and shape, ranging from a fraction of an inch to about 10 feet in thickness. The topaz bodies appear to lie in interesecting zones that strike northwest and northeast and dip nearly vertically. The nature of the occurrence and the distribution of andalusite and kyanite in the bedrock have not been studied. Angular fragments of topaz have accumulated in great abundance in the soil on the flanks of the ridge near the topaz zone. A study of the heavy minerals of minus 20-mesh size in the soil mantle showed them to be mainly topaz and kyanite; the latter ranged from 5 to 60 percent of the total heavy-mineral content (Fries, 1942, p. 73).

The reserves of topaz in the main bedrock deposit are estimated by Fries (1942), as follows:

Class of ore	*Tons of ore*	*Average topaz grade (percent)*	*Tons of topaz*
Probable	106,000	15	16,000
Possible	194,800	15	29,000

The average grade of the placer deposits was determined by taking samples from 23 pits that were dug to depths of 2 to 4½ feet. The content of topaz in 4 areas of placer ground was estimated by Fries (1942) to be 8,750 tons of coarse topaz (larger than a quarter of an inch), and 3,270 tons of fine topaz (under a quarter of an inch).

In 1950 and 1951, the Bureau of Mines drilled 10 diamond-drill holes here to explore 4 areas of topaz mineralization (Peyton and Lynch, 1953). The distribution of topaz and the Al_2SiO_5 minerals proved to be highly irregular. Determination of the content of aluminous minerals in the drill-core samples was difficult because of close similarities in their chemical composition and specific gravity. The topaz content was finally calculated on the basis of the fluorine content, and the combined kyanite and andalusite content was estimated on the basis of total alumina and petrographic and sink-float analyses. The analyses of samples from each drill hole are given in detail by Peyton and Lynch (1953). Out of a total of 231 core samples, 70 contain more than 15 percent combined topaz, andalusite, and kyanite.

Some indication of the relative content of aluminous minerals in these samples is also given in table 12, in which the analytical data of Peyton and Lynch (1953) have been arranged to show the percent of the total number of samples that have a certain mineral content.

TABLE 12.—*Distribution of topaz and andalusite-kyanite in drill-core samples, Brewer mine, Chesterfield County, S.C.*

Range in mineral content (percent)	Percent of samples per grade group	
	Topaz content	Andalusite-kyanite content
0– 4.9	66.7	63.5
5– 9.9	13.3	13.4
10–14.9	9.3	12.5
15–19.9	4.0	8.0
20–24.9	3.1	1.7
> 25	3.6	.9

BOLES MOUNTAIN, EDGEFIELD COUNTY

Boles (Strom) Mountain is a prominent east-trending ridge, over a quarter of a mile long and several hundred feet high, that lies about 1¾ miles northeast of the intersection of U.S. Highway 25 and South Carolina Highway 43. Andalusite and other aluminous minerals in quartzose rock were discovered here by us in March 1953. Most of the outcrops are along the western half of the ridge where they form bare rough ledges as much as 15 feet high and 30 feet wide; float rock is abundant on the eastern part of the ridge. Large amounts of float rock were gathered up 50 years or more ago by a Mr. Strom to build extensive walls and terraces around a large house and pavilion on top of the mountain.

Much of the rock is massive and light gray to tan. Some rock is composed of very fine grained quartz, pyrophyllite, and a little rutile. Andalusite and diaspore are commonly present (fig. 18). Pyrophyllite has replaced both andalusite and quartz, but it seems to have been about contemporaneous with diaspore. Kyanite is exposed in pyrophyllite-quartz rock at the western end of the ridge. Skeletal crystals of corundum in andalusite were observed in one thin section.

The Boles Mountain deposit may be a potential source of raw material for refractory or other ceramic uses. Its mineral composition is highly variable, however, and considerable exploration and sampling would be needed to determine the average alumina content and the size and shape of the deposit.

OTHER LOCALITIES

Quartz-pyrophyllite rock is found in an elliptically shaped area about 200 by 300 feet on Faulkner Mountain, a low conical knob that lies about 3½ miles N. 70° E. of Boles Mountain. The exposures are massive with rough limonite-stained surfaces. The rock is composed of very fine grained quartz cut by an irregular network of thin pyrophyllite veins; andalusite is a very rare constituent. The Boles Mountain and the Faulkner Mountain deposits are in the belt of volcanic rocks and slates that extends from the Little River region of Georgia across South Carolina (pl. 1). Schistose porphyritic and amygdular volcanic rocks were observed several miles northeast of Faulkner Mountain.

Small amounts of andalusite and pyrophyllite are present in quartzose rock on Parsons Mountains, a ridge about three-quarters of a mile long and 300 feet high, and about 6 miles south of the town of Abbeville. Gneissic quartzose rock with rough irregularly ribbed surfaces is exposed in low ledges across widths of 100 to 150 feet for a distance of nearly 1,000 feet southwest of the fire tower on the crest of the ridge; only a few outcrops and a little float are found north of the tower. The rock is made up of fine-grained quartz that is cut by small irregular stringers of pyrophyllite; andalusite grains are scattered through these veinlets and are partly replaced by pyrophyllite. Tiny needles of sillimanite(?) are sparsely distributed through the quartz. Coarse flakes of muscovite and small grains of yellow-brown rutile are also present. In an exposure along the road on the west side of the mountain, a soft white fibrous mineral occurs in small feathery clusters replacing quartz and muscovite; this mineral has the X-ray diffraction pattern of the paragonite type of mica (table 4).

Rock similar to that at Parsons Mountain occurs on a northeast-trending ridge in McCormick County, about 8 miles west-southwest of Parsons Mountain, 1½ miles northwest of Calhoun Mill, and just south of Little River.[13] Quartzite and sericite-quartz rock containing a little andalusite and pyrophyllite(?) are exposed in low ledges.

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[13] Knob marked 575 above sea level on the west edge of the Calhoun Creek, S.C., 7½-minute sheet (1949).

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