HIGH ALUMINA METAMORPHIC ROCKS OF THE KINGS MOUNTAIN DISTRICT, NORTH CAROLINA AND SOUTH CAROLINA

by

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The following evidence suggests that high alumina quartzite in this district is of metasedimentary origin: high alumina quartzite occurs as well defined thin beds that can be traced up to three and one half miles along strike; many outcrops of high alumina quartzite exhibit compositional layering (i.e., kyanite quartzite is interlayered with staurolite quartzite, and with non-kyanitic magnetiferous quartzite); high alumina quartzite beds occur in a conformable sequence of high alumina metasedimentary and metavolcanic schists. It is suggested that the high alumina quartzite beds are metamorphosed beds of sandy or silty clay; these beds probably represent one stage in the deposition of fine grained clayey clastic sediments.

No evidence was found to support the view of Smith and Newcombe (1951) that the kyanite at Henry Knob developed by hydrothermal introduction of alumina. The present study indicates that kyanite in the kyanite quartzite here, as throughout the district, is of metasedimentary origin.

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INTRODUCTION

General Statement

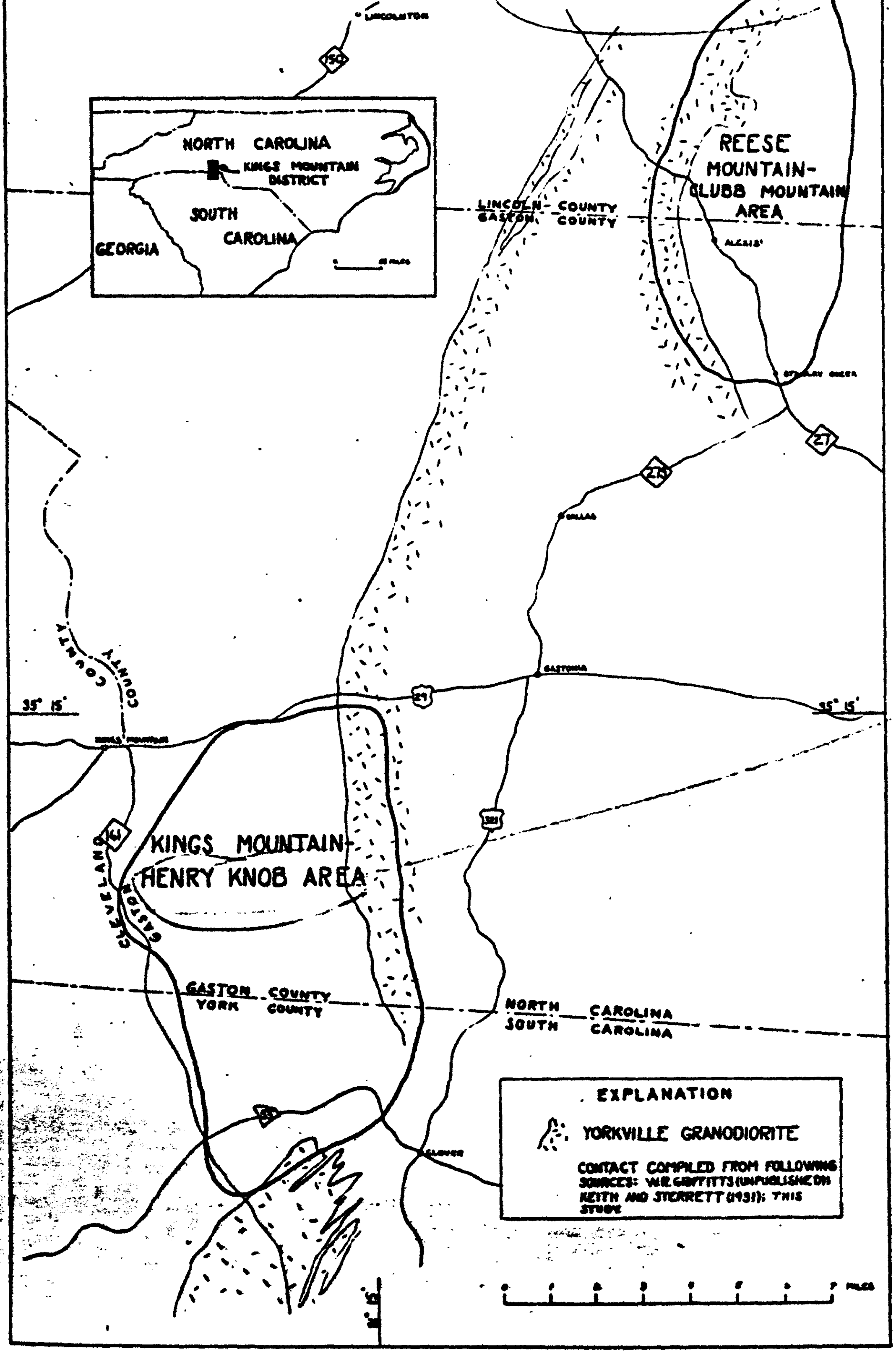
This report embodies a detailed field and petrographic study of the kyanite and sillimanite quartzite deposits and the related metamorphic and igneous rocks of the Kings Mountain district of North Carolina and South Carolina. The Kings Mountain district is situated at about the center of the Piedmont province in south central North Carolina and northern South Carolina (Figure 1).

This study is part of a United States Geological Survey project aimed at making a reconnaissance of all the kyanite deposits in the southeastern states, and at studying in detail the more important deposits.

The principal domestic sources of kyanite in the last five years have been from open pit operations at Baker Mountain, Virginia, and Henry Knob, South Carolina. While imports from India and Kenya supplied a very desirable kyanite aggregate for refractory use, the uncertainty of these imports motivated a search by the Survey for high grade domestic deposits. Indian kyanite is particularly desirable in that the interlocking texture and purity of the fine grained kyanite aggregates are such that the calcined product (mullite) consists of lumps of bonded crystals. By contrast, mullite formed from domestic kyanite is generally friable.

No kyanite ore resembling Indian kyanite was found in any quantity in the southeastern states. The reconnaisance and detailed mapping did, however, indicate the presence of millions of tons of kyanite quartzite in which the kyanite content varies from about 10 to 30 per cent.

FIGURE 1. INDEX MAP OF THE KINGS MOUNTAIN DISTRICT, NORTH CAROLINA AND SOUTH CAROLINA



Definition of Areas and Nature of Work

A reconnaissance of the Kings Mountain district was made by members of this Survey project in 1951. The detailed field work was done by the author during the period from October, 1951 through June, 1952. A detailed petrographic study was made of all the rock types during the winter of 1953-54.

Two areas, separated by a large body of granodiorite, were found to contain kyanite and sillimanite quartzite in the Kings Mountain district. These two areas are the Kings Mountain-Henry Knob area and the Reese Mountain-Clubb Mountain area, (Figure 1).

A. The Kings Mountain-Henry Knob area: This area includes a small part of the southwestern portion of Gaston County, North Carolina, and a small part of the northern portion of adjacent York County, South Carolina. The area lies in the northeast part of the Kings Mountain Quadrangle and includes a very small portion of the adjacent Clover and Gastonia Quadrangles to the east and northeast respectively. The geology in this area was mapped in detail on aerial photographs at a scale of 1:20,000, and then transferred to a planimetric base map prepared by the Trimetragon Branch of the Topographic Division of the Survey, (Plate I). Most geologic contacts on this map, with the exception of those involving the resistant high alumina beds, were drawn on the basis of outcrops in stream beds; little emphasis was put on soil types except where float could be identified, (see Weathering).

The following list of the principal kyanite and sillimanite quartzite deposits in this area indicates the mapping methods and scales at which the various deposits were mapped.

Deposit and locality	Type	Mapping method	Scale	Plate No.
Crowders Mountain-G	KQ	Aerial photo	1:20,000	I
The Pinnacle-G	KQ	Enlarged aerial photo	1:2400	V
Shelton property-G	KQ	Tape and compass	1:1200	IV
Will Knox property-G	SQ	Tape and compass	1:1200	VII
Ryan-Purcley property-G	SQ	Aerial photo	1:20,000	I
Henry-Knob-Y	KQ	Plane Table	1:1200	III

G = Gaston County, North Carolina

Y = York County, South Carolina

KQ = Kyanite quartzite

SQ = Sillimanite quartzite.

B. The Reese Mountain-Clubb Mountain area: This area is situated in the middle of the Gastonia Quadrangle about 15 miles northeast of the Kings Mountain-Henry Knob area. It lies partly in Lincoln County and partly in Gaston County, North Carolina. In this area only the high alumina deposits and the eastern contact of the Yorkville granodiorite were mapped on aerial photographs. The geology was transferred to a planimetric base map at a scale of 1:20,000, (Plate II). The other metamorphic and igneous rocks in this area were not studied in any detail. The area includes the kyanite quartzite deposit at Clubb Mountain and the sillimanite quartzite deposits at Reese Mountain and Machpelah Church. A large scale (1:1200) plane table map was made of the kyanite quartzite at the north end of Clubb Mountain, (Plate VI).

Previous work

Records of the occurrences of most of the high alumina minerals in the two areas, with the exception of sillimanite, are found in the early literature (Kerr, 1875; Genth and Kerr, 1881, Sloan, 1908). Reports on the granites of South Carolina and of the southeastern states (Watson, 1909, 1910) include references to plutonic rocks in the Kings Mountain-Henry Knob area. Early reports on the iron ores of North Carolina (Nitze, 1893) record the occurrence of magnetite and brown hematite in the Kings Mountain-Henry Knob area. A comprehensive study of the general geology and ore deposits of the Kings Mountain-Gaffney Quadrangles was made by Keith and Sterrett (1931).

Manganese deposits, which occur as septa in the Yorkville granodiorite in the Kings Mountain-Henry Knob area, were investigated by White (1944) as part of a broader study of the manganese deposits of North Carolina.

Barite deposits which occur east and southeast of Crowders Mountain have been investigated in a study of barite deposits of the Carolina Barite Belt (Van Horn, Le Grand and McMurray, 1949).

The kyanite deposit at Henry Knob was studied by Newcombe (1949) and a discussion of the origin of this deposit is given by Smith and Newcombe (1951). Aside from their study and the general mapping by Keith and Sterrett (1931) no detailed work has been done on the high alumina deposits. The sillimanite quartzites were unknown prior to a reconnaissance by Espenshade in 1951.

Regional Geologic Setting

The Piedmont province is, with the exception of the fault-block basins of Triassic sedimentary and volcanic rocks, underlain entirely by metamorphic and igneous rocks. The metamorphic rocks and many of the bodies of igneous rocks have a general northeast trend which parallels that of the Appalachian Mountain system.

The principal metamorphic rock types in the Piedmont are biotite and muscovite schist and gneiss, hornblende gneiss and slate. In general these metamorphic rocks indicate a higher degree of metamorphism than do the bulk of schists and gneisses of the central and northern Blue Ridge to the northwest. This higher degree of metamorphism is in large part the result of the intimate association of various sized bodies of plutonic rocks which range in composition from gabbro to granite. Large bodies of rock, ranging in composition from granodiorite to granite, are particularly numerous and are commonly accompanied by pegmatites.

Some of the lowest grade metamorphic rocks in the Piedmont are found in two long belts of metavolcanic rocks that extend from southern Virginia through eastern North Carolina to the northern part of South Carolina. These rocks have been referred to as the "Volcanic-slate series", or "Carolina slates" (Pogue, 1910; Laney, 1910; Laney 1917; Stuckey, 1928; Broadhurst and Councill, 1953). They consist in large part of metamorphosed tuffs, volcanic breccias and flows, and fine grained sedimentary rocks. Numerous pyrophyllite deposits occur in the volcanic-slate series. The western-most belt of the volcanic-slate series lies 30 miles east of the Kings Mountain-Henry Knob area. The Kings Mountain-Henry Knob area contains metavolcanic rocks which have several features in common with the volcanic rocks of the volcanic-slate series. These features are discussed later under the heading "Age and Regional Correlation".

Kyanite quartzite occurs at several localities in the Piedmont from central Virginia to Georgia. Several deposits occur within the belts of the volcanic-slate series. The evidence suggests that these deposits were formed by local replacement of the rocks in the volcanic-slate series. The major economic deposits of kyanite quartzite occur west of the two belts of the volcanic-slate series. These deposits include those at Baker Mountain and Willis Mountain, Virginia, and those in the King Mountain district, North Carolina and South Carolina. The evidence suggests that these deposits were formed by the metamorphism of high alumina sedimentary rocks.

Kyanite and sillimanite are widespread in the schists and gneisses of the Piedmont. Sillimanite is particularly abundant in the schists that form a long belt extending for 80 miles southwest from central North Carolina into South Carolina, (Hunter and White, 1946; Hash and Van Horn, 1951).

The geologic map of the Kings Mountain and Gaffney Quadrangles (Keith and Sterret, 1931) indicates that the schists, gneisses, conglomerates and high alumina quartzites in the Kings Mountain-Henry Knob area are part of a large, well defined northeast-trending belt of metamorphic rocks. This belt is from five to ten miles wide and at least 35 miles long. It extends from Gaffney, South Carolina northeast through four quadrangles. The Kings Mountain-Henry Knob area is situated on the east side of this belt about midway between the ends of the belt.

The major rock types exposed in this belt in the Kings Mountain and Gaffney Quadrangles are listed below in order of their occurrence across the strike of the belt from southeast to northwest. The formation names in brackets are those of Keith and Sterrett (1931). "K-H" indicates that the rock occurs in the Kings Mountain-Henry Knob area. The figure following the formation name indicates the width of the exposure of this unit. Isoclinal folds with steep axial planes are characteristic of this region; so the thickness of these units may be one-half or only a small fraction of the width of the exposure.

K-H Biotite schist and gneiss (metavolcanic and metasedimentary), minor hornblende gneiss, metamorphosed oligoclase tonalite [Bessemer Granite] 20,000-21,000 feet.

K-H Fine grained mica[1] schist and phyllite (metavolcanic and metasedimentary), [Battleground schist] 10,000-15,000 feet.

K-H Kyanite conglomerate and kyanite quartzite [kyanite quartzite member of the Kings Mountain formation] 20-170 feet. This unit occurs at only two localities in the belt southwest of the Kings Mountain-Henry Knob area. It has its maximum development in the Kings Mountain-Henry Knob area.

K-H Manganiferous schist [manganiferous schist member of the Battleground schist] 100-1,000 feet. This unit is discontinuous but crops out in a consistent stratigraphic position over a distance of 25 miles.

K-H Coarse non-kyanitic conglomerate, chloritic quartzite, chloritoid-mica schist [Draytonville conglomerate, Kings Mountain quartzite]. The width of conglomerate exposures ranges from 20 to 300 feet; quartzite exposures range from about 100 to 1,000 feet in width. The quartzite is discontinuous and not generally a good marker; the conglomerate is also discontinuous but is an excellent marker unit for more than 25 miles. Deposits of magnetite and brown hematite occur sporadically along the entire belt of metamorphic rocks. Many of these deposits in the Gaffney and Kings Mountain Quadrangles occur at about this interval in the sequence of rocks.

1. All white mica, unless inferred from chemical analysis or optical properties to be muscovite, is referred to as "mica". See discussion under Chloritoid Schist.

Hornblende gneiss [Roan gneiss] 200-8500 feet.

Folded beds of quartzite, biotite schist and gneiss, fine grained mica schist, phyllite and marble [Kings Mountain quartzite, Carolina gneiss, Blacksburg schist, Gaffney marble] 2,000-5,000.

The outcrop pattern of these various units, and especially the conglomerate, quartzite, marble and manganiferous schist, indicates the presence of several long narrow folds in this belt.

The Kings Mountain-Henry Knob area is bordered on the east by a large body of granodiorite [Yorkville granite of Keith and Sterrett, 1931]. The contact of this body in this area trends north, and there is considerable evidence to indicate that the emplacement of the granodiorite was accompanied by folding and shearing of the metamorphic rocks along planes parallel to this contact. Thus, the Kings Mountain-Henry Knob area is situated in a zone between two converging major structures: the northeast-trending belt of metamorphic rocks, and the north-trending contact of the Yorkville granodiorite.

The high alumina rocks and associated schists in the Reese Mountain-Clubb Mountain area lie on the east side of the large granodiorite body, 15 miles northeast of the Kings Mountain-Henry Knob area. It is probable that the metamorphic rocks in the Reese Mountain-Clubb Mountain area are a continuation of the well defined northeast-trending belt of metamorphic rocks in the Kings Mountain-Henry Knob area.

The regional distribution of pegmatites is interesting in that pegmatite bodies are absent or occur only rarely throughout much of the area where kyanite quartzite is abundant in the Kings Mountain-Henry Knob area. The principal occurrences of pegmatites in this area are: (1) Small dikes and sills in the metamorphic rocks within about 2,000 feet of the Yorkville granodiorite contact, and (2) A well defined narrow zone of tin-spodumene pegmatites that lies immediately west of the major northeast-trending belt of metamorphic rocks (Griffitts and Olsen, 1953, p. 211). This zone of pegmatites is about three miles west of The Pinnacls. Pegmatite dikes and sills are abundant throughout a large area west of the tin-spodumene pegmatite zone.

GENERAL DESCRIPTION

Topography

The general accordance of the summits of the gently rolling interstream areas of the Piedmont province suggeststhat these areas are partly dissected remnants of a broad surface of low relief. In general, the relief on this surface is about 50 feet or less over a distance of a few miles. In the Kings Mountain district the elevation of this surface is different in one broad area compared to another depending on the underlying bedrock. Thus, the broad areas underlain by the Yorkville granodiorite have elevations ranging from 750 to 850 feet compared to areas underlain by quartzose schist and gneiss and quartzite with elevations ranging from 850 to 950 feet. The latter areas are usually narrow and elongated parallel to the general grain of the metamorphic rocks.

In the northwestern part of the Kings Mountain-Henry Knob area many long hills and ridges rise abruptly 100 to 800 feet above the surface of low relief. The principal hills include Crowders Mountain, The Pinnacle, and the north end of the Kings Mountain range. Henry Knob is an isolated hill in the southeastern part of the area. Most of the prominent hills in the area are underlain by kyanite quartzite, fine grained quartzose schists, or 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 hills underlain by kyanite quartzite are usually craggy, and precipitous cliffs are common. The slopes of these hills are heavily mantled with kyanite-quartzite talus.

Hills underlain by sillimanite quartzite rise only 50 to 120 feet above the surface of low relief and are not conspicuously elongated.

The fact that both sillimanite and kyanite quartzite beds form most of the prominent hills is a great aid in reconnaissance mapping.

Weathering

Intense chemical weathering of the rocks at or near the surface is characteristic of the Piedmont province. In the Kings Mountain district, weathering extends to depths of 25 to 50 feet and, locally, to 200 feet. In general, exposures of fresh rock are found only in the numerous small streams and along the crests of prominent hills. Weathering has altered feldspar to clay and produced a partial chemical breakdown of most minerals with the exception of quartz, mica,* the high alumina silicate minerals, and zircon. These unaltered minerals can be recovered by panning the weathered rock, and this provides a valuable aid in mapping. Although highly weathered, the structure and texture of many schists and gneisses are commonly preserved.

The development of hills in the northwestern part of the area is apparently related to two principal factors: the presence of resistant minerals, and the texture of the underlying rock. Kyanite quartzite owes its resistance to two chemically resistant minerals, quartz and kyanite, but especially kyanite. Differential resistance to weathering of quartz and kyanite (or sillimanite) is evident from nearly every outcrop where the minerals are exposed together. Kyanite and sillimanite project above the weathered surface of the quartzite groundmass and give the rock a rough pitted surface. The resistance of kyanite quartzite to weathering is also increased in some cases by the presence at the surface of a resistant limonitic weathering crust that has been produced by the hydration of pyrite in the rock.

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* All white mica, unless inferred from chemical analysis and optical data to be muscovite, is referred to as "mica". See discussion under Chloritoid Schist.

The combination of chemically resistant mica and quartz and the fine grain size of some quartzose schists in the northwestern part of the area makes them prominent ridge-formers.

The color and texture of many soils produced by intense chemical weathering are diagnostic of the parent rock type. Thus, a dark brown or black soil is formed from manganiferous schist, a dark red or reddish-brown soil is characteristic of hornblende gneiss, and light-brown sandy soil is characteristic of granite rocks. In addition, the presence of resistant minerals and float fragments of relatively unweathered rock identify the parent rock type of many soils. Rock fragments are common in soils derived from hornblende gneiss, quartz-mica schist, quartzite, and diabase. The areal distribution of float is in many cases the only indication of the extent of the outcrop from which the float was derived. Contacts drawn on the basis of soil and float are generalized and indicate little of the true nature or exact extent of the contact. Many geologic contacts in interstream areas north of Henry Knob are of this nature.

General Geology

Unless otherwise stated, descriptions of the metamorphic rocks refer to the Kings Mountain-Henry Knob area (Plate I) where the detailed mapping was done. Table I is a summary of the geologic history in this area. Figure 2 is a simplified sketch of the major structure of the area.

The large area north of Henry Knob is underlain by biotite schist and gneiss, hornblende geniss and metamorphosed oligoclase tonalite. Overlying these apparently older rocks, and defining a large north-plunging anticline (I, Figure 2), is a sequence of fine grained schistose

TABLE I

Summary of the geologic history of the Kings Mountain-Henry Knob area. The oldest event is at the bottom of the column. The names in parentheses indicate the metamorphic rock derived from the original rock.

7. Intrusion of diabase dikes.

6. Emplacement of the Yorkville granodiorite: intense deformation, major metamorphism.
(early 6?)

5. Deformation: development of major folds.

4c. Eruption and deposition of pyroclastic material (schistose pyroclastic rocks) and basic volcanic rocks (hornblende gneiss); deposition of fine grained clastic sediments (fine grained mica schists); deposition of manganiferous sediments (manganiferous schist).

4b. Deposition of ferruginous sandstone or ferruginous chert (magnetiferous quartzite and hematite schist; deposition of clay-rich sandstone and conglomerate (kyanite quartzite, kyanite conglomerate, sillimanite quartzite, kyanite-staurolite-chloritoid quartzite); deposition of fine grained clayey sandstone and tuffaceous material (chloritoid schist, quartz-mica schist, chlorite-mica schist, fine grained quartzite).

4a. Deposition of clay-rich sandstone (kyanite quartzite and sillimanite quartzite). Eruption and deposition of pyroclastic material (schistose pyroclastic rocks); eruption of volcanic rocks of intermediate to rhyolitic composition (albite-chlorite gneiss, biotite gneiss); deposition of fine grained ferruginous sandstone, tuffaceous material and other fine grained clastic sediments (fine grained quartzite, mica schist).

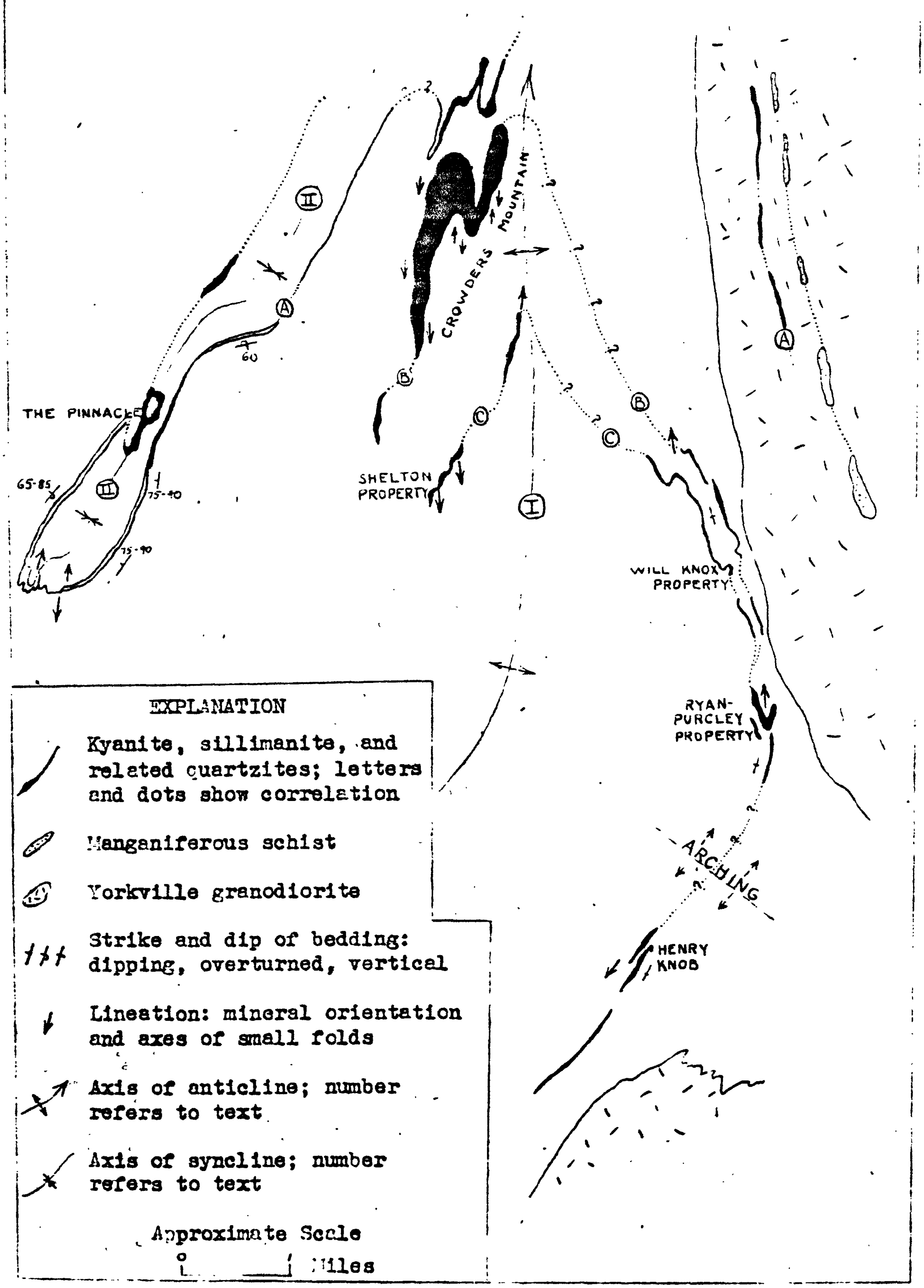
3. Weathering and erosion; development of unconformity.

2. Local intrusion of quartz gabbro near Henry Knob (hornblende gneiss).

1a. Intrusion of oligoclase tonalite (metamorphosed oligoclase tonalite and biotite gneiss); local albitization of oligoclase tonalite and rocks that are now biotite gneiss and hornblende gneiss.

1. Eruption of volcanic rocks: soda rhyolites (biotite schist and gneiss), andesite and basalt (hornblende gneiss); deposition of conglomerate and other clastic sedimentary rocks (conglomeratic biotite schist) which are interlayered with the volcanic rocks.

Figure 2. STRUCTURAL SKETCH MAP OF THE KINGS MOUNTAIN-HENRY KNOB AREA



pyroclastic rock, chloritoid schist, magnetiferous quartzite, kyanite (and sillimanite) quartzite and manganiferous schist.

Kyanite quartzite and sillimanite quartzite occur as relatively thin beds in a thick sequence of high alumina schists. Kyanite quartzite beds range from about 10 to 170 feet in thickness. Sillimanite quartzite beds range from about 5 to 40 feet in thickness and are generally more lenticular than the kyanite quartzite beds. In both the Kings Mountain-Henry Knob and Reese Mountain-Clubb Mountain areas sillimanite quartzite occurs within about 3000 feet of the Yorkville granodiorite contact. Kyanite quartzite occurs as far as four miles from the contact. Some of the kyanite quartzite and kyanite conglomerate beds can be traced along strike for distances up to three and one-half miles. Chloritoid and staurolite are locally abundant in some kyanite quartzite beds, and in several cases staurolite quartzite, magnetiferous quartzite and kyanite quartzite occur as highly folded interlayers.

The Yorkville granodiorite is an unmetamorphosed coarse grained porphyritic rock that crops out along the eastern and south-eastern part of the area. These exposures mark the western margin of a large body or series of bodies that trend north-northeast for a distance of more than 55 miles.

The presence of numerous long septa of manganiferous schist, sillimanite schist, hornblende gneiss, etc, in the Yorkville granodiorite suggests that the granodiorite was intruded into the east limb of the major anticline (I, Figure 2). In the northwestern part of the area, on the west flank of the anticline, a large syncline (II, Figure 2) is defined by the outcrop pattern of the kyanite quartzite and kyanite conglomerate beds. This fold has a sinuous trend and can be traced for about four miles.

Several structural and mineralogical features indicate that the rocks in this area have undergone at least two major deformations. The development of large folds (Figure 2) preceded the emplacement of the Yorkville granodiorite which was accompanied by a major deformation and metamorphism. Some of the products of this last deformation include the profuse small folds especially well developed in kyanite quartzite, and the strong linear structures and flow cleavage prominent throughout the area. This flow cleavage, striking north-northeast, transects both limbs of the northeast-trending syncline (II).

The metamorphism that accompanied the emplacement of the Yorkville granodiorite produced rocks of the amphibolite facies (Turner, 1948, p. 76) in the septa and along the margins of the granodiorite. The schists and high alumina quartzite in the vicinity of The Pinnacle and the Kings Mountain range belong to the greenschist and albite-epidote-amphibolite facies. The biotite schist and gneiss and hornblende gneiss in the large area north of Henry Knob also indicate an increase in metamorphic rank from greenschist and albite-epidote-amphibolite facies in the west to amphibolite facies in the east, near the Yorkville granodiorite contact.

Intrusion of diabase dikes, probably of Triassic age, represents the closing episode in the igneous history of the area. In general the dikes were emplaced with only minor structural disturbance. They have a general northwest trend.

Deposits of gold and barite occur in the Kings Mountain-Henry Knob area. The gold deposits have proved to be of little value in this area, but the barite deposits have been extensively prospected, and a barite mine east of Crowders Mountain was operated for some time.

Age and Regional Correlation of Igneous and Metamorphic Rocks

No direct evidence was obtained during the present study to indicate either the geologic age or a regional correlation for the metamorphic rocks in the Kings Mountain-Henry Knob area.

There are some general and specific lithologic similarities between some of the rocks of the Kings Mountain-Henry Knob area and those in the belts of the volcanic-slate series. The nearest known exposure of the volcanic-slate series is about 30 miles east of the Kings Mountain-Henry Knob area, and it must be stressed that the nature of these similarities summarized below affords only a "best guess" type of correlation. The following features are characteristic of some of the rocks in the Kings Mountain-Henry Knob area and they are unique in this general part of the Piedmont: (1) the metamorphic rocks occur in a long, well defined belt (see Regional Setting) and have been folded into long tight folds; (2) well defined bedding is prominent through much of this belt; (3) the metamorphic rocks of volcanic origin show distinct relict phenocrysts and volcanic textures; these volcanic rocks indicate a low minimum degree of metamorphism. The combination of these features suggests that these rocks are of similar origin and, perhaps, age as the schists in the volcanic-slate series. The volcanic-slate series has yielded no fossils (Eardley, 1951, p. 114), and is probably of late pre-Cambrian or Paleozoic age (Eardley, 1951, p. 114; King, 1951, p. 136).

The age of the Yorkville granodiorite is not known from any geologic relations or radioactivity measurements. It is a large unmetamorphosed plutonic body intrusive into the metamorphic rocks along the east side of the Kings Mountain-Henry Knob area. Unmetamorphosed batholiths are not uncommon in the Piedmont (Eardley, 1951, p. 110), and many, if not most, of these are probably of Paleozoic age (Eardley, 1951, p. 111; Willis and Willis, 1941, pp. 1643-1684). If the lack of metamorphism of the Yorkville granodiorite can be taken as an indication of its emplacement late in the geosynclinal development, this plutonic body is probably of late Paleozoic age.

METAMORPHIC ROCKS

Biotite Schist and Gneiss

Introduction

Fine to medium grained* biotite schist and gneiss are the most abundant rock types in the Kings Mountain-Henry Knob area. Biotite schist and gneiss form the bulk of the rock exposed in the core of the anticline (I, Figure 2) between Henry Knob and Crowders Mountain. In this area biotite schist and gneiss are intruded by coarse grained oligoclase tonalite, and interlayered with hornblende gneiss and quartz-mica** schist. Biotite schist and gneiss also occur in a belt just west of the Yorkville granodiorite contact, north of McGill Creek and south of Crowders Creek. The rock in this belt is associated with fine grained hornblende-epidote gneiss. Biotite schist and gneiss are common as long narrow septa in the Yorkville granodiorite. Two narrow belts of fine grained biotite gneiss occur in the northwestern part of the area.

Keith and Sterrett (1931) mapped nearly all the biotite schist and gneiss in the area as Bessemer granite, and stressed the point that much of the coarse grained granite was sheared and metamorphosed to fine grained schist and gneiss. In the present study an attempt was made to distinguish the distinctly coarse grained granitic textured rock (oligoclase tonalite) from fine grained biotite schist and gneiss.

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* The following grain size scale is used in this thesis:

Diameter of grain	Classification
Less than 0.1 millimeter	Very fine grained
0.1 to 1 millimeter	Fine grained
1 to 3 millimeters	Medium grained
More than 3 millimeters	Coarse grained

** All white mica, unless inferred from chemical analysis or optical data to be muscovite, is referred to as "mica". See discussion under Chloritoid Schist.

In addition to biotite schist and gneiss produced by the shearing of oligoclase tonalite, the area includes biotite schists and gneisses derived from volcanic rocks and conglomeratic sedimentary rocks.

General Features

In general, the biotite schists and gneisses are fine to medium grained, medium gray to light gray rocks. Foliation is well developed. Biotite occurs evenly disseminated or as clusters or smears along the foliation planes which are spaced 1 to 3 millimeters apart. The principal constituents are quartz, plagioclase (albite to calcic oligoclase and, in one case, bytownite), biotite (locally altered to chlorite), muscovite and, occasionally, microcline or orthoclase. Sillimanite, garnet, and staurolite occur in schist in the central and eastern part of the area. Common accessory minerals are epidote, magnetite, pyrite and apatite.

The detailed discussion that follows is divided into two parts:

A. Description of lower grade schist and gneiss according to parent rock type. These rocks have relict sedimentary and igneous textures and are largely, though not entirely, restricted to the western and west-central part of the area where the grade of metamorphism was equivalent to the albite-epidote amphibolite facies (Turner, 1948, p. 90).

B. Description of higher grade biotite schist and gneiss that occur as septa in the Yorkville granodiorite, and in the central part of the area as far as one and one half miles west of the granodiorite contact. In general these rocks are the higher grade (amphibolite facies) equivalents of those discussed under the first heading.

Description of Lower Grade Schist and Gneiss According to Parent Rock

Orthogneiss and Schist

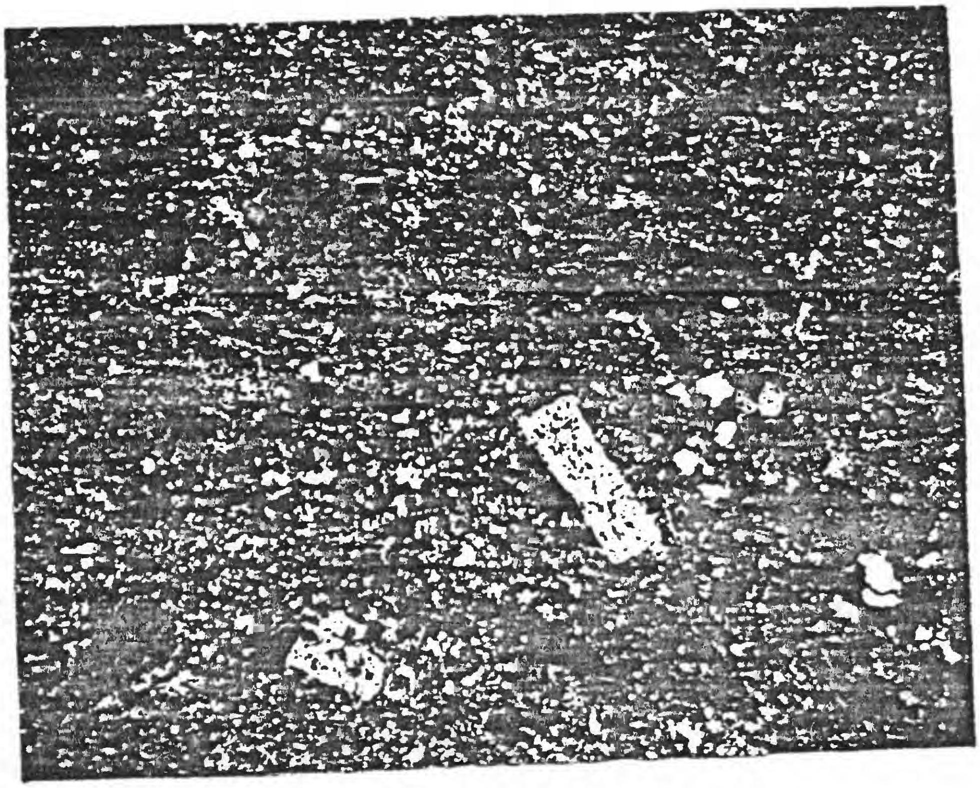
Three types are distinguished: (1) metamorphosed porphyritic volcanic rock, (2) metamorphosed fine grained leuco-tonalite, and (3) metamorphosed coarse grained oligoclase tonalite.

Biotite schist and gneiss, showing relict porphyritic texture (Figure 3), crops out at many scattered localities in the large area north and northwest of Henry Knob. It is apparently interlayered with biotite schist and gneiss derived from conglomeratic sedimentary rocks, and hornblende gneiss derived from intermediate to basic volcanic flows. The two long thin bodies of biotite gneiss, in the northwest part of the area, are interlayered with fine grained chloritoid schist and quartz-mica schist. These two biotite schist bodies may represent one volcanic flow which has been metamorphosed and folded into a syncline (II, Figure 2) along with kyanite quartzite and conglomerate.

Much of this type of biotite schist is characterized in thin section by the presence of medium grained (up to 2 millimeters) plagioclase (albite to sodic oligoclase) crystals set at random in a matrix of very fine grained (0.01-0.09 millimeters) quartz and plagioclase and, locally, microcline. The coarser grained random relict phenocrysts (Figure 3) generally contain fine grained inclusions of white mica, epidote and quartz. They invariably have irregular, ragged edges and occasionally have embayments of fine grained quartz and plagioclase. Polysynthetic twinning is generally absent or very fuzzy and irregular. Biotite is usually brown or reddish brown, and, rarely, olive green. There seems to be no consistent color variation with respect to degree of metamorphism. Biotite is disseminated through the rock or restricted to

Figure 3. Photomicrograph of metavolcanic biotite gneiss. Sample from creek bed 1,000 feet southeast of Bethany Church, Foliation produced by fine grained biotite and mica; phenocrysts are sodic oligoclase; groundmass is quartz, oligoclase and some potash feldspar. Crossed nicols, X 25.

Figure 4. Photomicrograph of metavolcanic hornblende gneiss. Sample from creek bed about one mile south-southwest of Crowders Mountain Village. Most of the dark minerals are hornblende; phenocrysts and feldspar laths in groundmass are albite; very fine grained, light colored minerals are quartz. Crossed nicols, X 25.



well defined foliation planes. Muscovite occurs as small flakes intergrown with biotite or, in the more highly metamorphosed rocks, as coarse random, sometimes ragged flakes. Epidote is a common accessory. It sometimes constitutes up to 1 to 2 per cent of the rock. It occurs as small scattered euhedra or as coarse aggregates of anhedra replacing plagioclase. Other accessory minerals include magnetite, zircon, tourmaline, apatite, sphene, pyrite.

Albitization.

A chemical analysis of fine grained gneiss, from the vicinity of Trinity Church, is given in Table II. No attempt was made to make an accurate modal analysis of thin sections of the rock from which this chemical analysis was made because of the very fine grained nature of the quartz-albite (Ab 95-98) groundmass. It was estimated from three thin sections that very fine grained quartz and albite constitute from about 80 to 90 per cent, and coarser relict plagioclase (now albite) phenocrysts (up to 1.6 millimeter long) less than 1 per cent, of the rock. The very fine grained albite-quartz aggregate occurs as broad streams and fingers oriented parallel to the foliation. Biotite and chlorite make up 5 to 10 per cent of the rock. Some of the chlorite appears to have replaced biotite but most of it occurs as discrete flakes or sharp intergrowths with biotite. Accessory minerals include muscovite, pyrite, magnetite, epidote, apatite, and tourmaline. Biotite and moderately coarse grained quartz are concentrated along well developed foliation planes.

The CaO content (2.29 per cent) of this albite-biotite gneiss cannot be accounted for by the albite, epidote and apatite seen in thin section. A calculation, based on the major oxides of the chemical

TABLE II

Chemical analysis of biotite gneiss from an outcrop 2200 feet N70W of Trinity Church, Gaston County, North Carolina. Sample composed of six specimens taken across strike over a distance of 100 feet. Analyst: Lucille N. Tarrant, U.S. Geological Survery.

SiO_2	70.52
Al_2O_3	14.67
Fe_2O_3	.68
FeO	2.77
MgO	1.60
CaO	2.29
Na_2O	4.64
K_2O	1.34
H_2O-	.03
H_2O+	.59
TiO_2	.42
CO_2	.02
P_2O_5	.08
S	.38
MnO	.05
	100.08
Less O for S	.10
	99.98

analysis (Table II), indicates that the specimens from which the chemical analysis was made probably contained about 3 per cent epidote—or 2.5 per cent more epidote than was seen in thin section. Such local variation in epidote content is characteristic of the hornblende gneiss in this vicinity. Thin section study indicates that most, if not all, of the Na_2O is in the form of albite.

The high $Na_2O:K_2O$ ratio (3.5:1) of this gneiss is also a characteristic of the metavolcanic biotite gneiss as a whole, oligoclase tonalite (5.3:1), and leuco tonalite (see beyond).

In the case of the biotite gneiss under consideration, the following features suggest albitization of the rock:

(a) The rock crops out within 2000 feet of albitized basic volcanic rocks (see Hornblende Gneiss).

(b) The interfingering texture of the very fine grained quartz-albite aggregate suggests introduction of material rather than recrystallization of a fine grained groundmass.

Is this albitization a feature that accompanied metamorphism, or the intrusion of diabase dikes, or is it related to some pre-metamorphic event? Pervasive soda metasomatism quite certainly did not occur during the major metamorphism that attended the emplacement of the Yorkville granodiorite for such highly susceptible rocks as the high alumina quartzites and quartz gabbro show no sign of albitization (see Metamorphism). Although albitization is best shown in the immediate vicinity of a diabase dike south of Trinity Church, there are instances of albitization as far as 3000 feet from diabase dikes, and in general there seems to be no space relation between the two. A diabase dike cuts kyanite quartzite at Henry Knob yet no albitization or other alteration of the kyanite was seen. Albitization may have occurred during a metamorphism prior to the deposition of the high alumina quartzites but this is thought to be less likely than the theory advanced below.

The sodic character of the schists and local albitization may be related to the initial igneous episode which included the eruption of volcanic rocks and emplacement of the associated oligoclase tonalite. Inferring from the metamorphic rocks, the following rock types were present in the igneous complex: soda rhyolites (bulk of metavolcanic biotite schist), basalt and andesite (bulk of hornblende gneiss), and soda-rich intrusive rock (oligoclase tonalite). Local albitization of biotite gneiss, hornblende gneiss, and oligoclase tonalite was probably produced by hydrothermal emanations from the magma of the soda-rich oligoclase tonalite. (see Oligoclase Tonalite)

(2) Fine grained biotite gneiss, apparently developed from leucotonalite, crops out in Crowders Creek about three-quarters of a mile west of Crowders Mountain Village, and in a small stream bed three-quarters of a mile southwest of Unity Church. The field relations of this rock are not known, but in each case it occurs in a large belt of metavolcanic biotite gneiss.

From 75 to 80 per cent of this rock consists of fine grained random albite crystals. The albite twinning in these crystals is very ragged and fuzzy. Fine grained interstitial quartz constitutes about 20 per cent of the rock. Accessory minerals include biotite, chlorite, epidote, magnetite, muscovite and apatite.

The random orientation of the fine grained albite crystals and the interstitial position of the quartz suggest an igneous texture. The lack of much associated epidote suggests that the original plagioclase was soda-rich. It is probable that this rock is the fine grained equivalent of the oligoclase tonalite.

(3) North of Henry Knob, near Fairview School, some of the biotite schist has developed by metamorphism of coarse grained oligoclase tonalite. The distinction between oligoclase tonalite and biotite schist was made in the field on the basis of grain size and texture. The oligoclase tonalite is a coarse grained non-foliated light gray rock with biotite concentrated in patches.

In the development of biotite schist from this rock, the biotite has been more evenly distributed along closely spaced foliation planes, the coarse oligoclase crystals have been recrystallized to smaller (0.2 to 0.3 millimeters) clear anhedra with well developed twinning; the quartz phenocrysts, so characteristic of the oligoclase tonalite, have been recrystallized to irregular aggregates of fine grained anhedra. Another characteristic of this type of schist is the presence of thin "skins" of mica along incipient foliation planes.

The areal extent of biotite schist derived from coarse grained oligoclase tonalite is not known but it may be large.

Paragneiss and Schist. The principal metasedimentary type (1) is metaconglomerate. Another type (2), containing bytownite, is believed to be a metasediment. It was found at only one locality.

(1) At five widely scattered localities in the large area north of Henry Knob the biotite schist is distinctly conglomeratic. The pebbles vary from a fraction of one inch to 10 inches in length. They are flattened in the plane of foliation and consist, for the most part, of fine grained biotite schist, biotitic quartzite and hornblende gneiss.

In thin section, the fine grained groundmass of this schist resembles the groundmass of the orthogneiss. Two thin sections have the following estimated modal range:

quartz	50 to 70 per cent
microcline and orthoclase	10 to 35 per cent
biotite	5 to 15 per cent
muscovite	1 to 5 per cent

accessory magnetite, epidote, garnet and pyrite

(2) Bytownite-bearing biotite schist crops out at one point on the South Fork of Crowders Creek, 2.8 miles northeast of Henry Knob. The outcrop is 100 feet west of the Yorkville granodiorite contact and 100 feet east of a diabase dike. In thin section bytownite, An 75-80, is seen to occur as fine grained evenly distributed anhedra. Quartz is generally fine grained, but also occurs as coarse angular grains up to 6 millimeters in diameter. Two thin sections have the following estimated mode:

quartz	30 to 50 per cent
bytownite	30 per cent
biotite	5 to 20 per cent
sillimanite	5 per cent
muscovite	1 to 3 per cent

accessory garnet and pyrite

This interesting mineral assemblage probably reflects the composition of a lime-rich parent sediment. The absence of epidote is curious and may indicate a low water content during metamorphism. The possibility that the bytownite is a metasomatic product cannot be denied, but study of the entire area indicates that neither diabase nor the Yorkville granodiorite effected lime metasomatism. Furthermore, epidote might be the more logical product of lime metasomatism than anhydrous bytownite.

Description of Higher Grade Biotite Schist and Gneiss

The textural and mineralogical characteristics of the schists and gneisses that occur as septa in the Yorkville granodiorite, and in the central part of the area as far as one and a half miles west of the granodiorite contact, indicate a higher grade of metamorphism than recorded by the same schists and gneisses in the western part of the area. Some gradational rocks are found in the central part of the area.

The more thorough recrystallization of these higher grade schists is indicated by the absence of pebbles, the lack of blastoporphyritic texture, a slight but general coarsening and equalization of grain size, and the presence of such varietal minerals as staurolite, garnet and sillimanite.

With the exception of the septa, which are considered later, these higher grade biotite gneisses contain about equal amounts of quartz and sodic to calcic oligoclase which together generally make up 80 to 90 per cent of the rock. Foliation is commonly pronounced. Microcline is generally absent but locally makes up 5 per cent of the rock. The color of the biotite is generally brown and rarely olive green. Biotite content ranges from about 2 to 10 per cent. Chlorite occurs in minor amounts as discrete flakes, intergrown with biotite, and as an alteration of biotite. Muscovite content varies from traces to 25 per cent. In several cases it has grown athwart the foliation planes and appears very ragged.

Accessory minerals include magnetite, epidote, apatite, pyrite, zircon, sphene and rutile.

When present, garnet occurs as fine grained anhedra to euhedra and is sometimes conspicuously concentrated in the biotite folia. Staurolite was seen in one thin section as fine grained ragged poecilo-blastic anhedra intimately intergrown with biotite. Euhedral garnet occurs in the same rock but the relation between garnet and staurolite is not clear. Sillimanite occurs as very fine grained prisms which commonly form tufted aggregates. In the incipient stages of development, sillimanite aggregates occur along quartz and oligoclase grain boundaries and as inclusions in muscovite. As the sillimanite content increases these aggregates form more or less continuous matts that lie in the plane of foliation.

The distribution of garnet is not well known. It was not found farther than 2 miles west of the granodiorite contact. Sillimanite, with one exception, occurs only within about 3,000 feet of the granodiorite contact. The mode of development of sillimanite is discussed under Metamorphism.

Potash Metasomatism.

The mineralogy of the biotite schists in the vicinity of the Lawton and Chimney Place barite deposits indicates that barite mineralization was probably accompanied by potash metasomatism. (See also Metamorphism.) The unaltered schist taken from a large dump at the Lawton Barite mine, southwest of Gassett Lake, consists of andesine, quartz, and biotite with accessory quantities of garnet, fine grained mica, staurolite, zoisite, piedmontite (minor) and apatite. Muscovite and epidote are locally very abundant in the schist. In some thin sections, untwinned potash feldspar constitutes about 75 per cent of the rock. Thin veins consisting of adularia, calcite and highly pleochroic epidote, cut this high potash rock.

In a biotite schist from the vicinity of the Chimney Place property (1.8 miles south of the Lawton mine) microcline is locally abundant. It is abundant in the fine grained groundmass with quartz. Microcline also forms veins in relict plagioclase phenocrysts and partially replaces the phenocrysts pseudomorphically.

Septa in the Yorkville Granodiorite.

Long narrow steeply dipping bodies of quartz-biotite schist, sillimanite-biotite gneiss and sillimanite-biotite-garnet schist are abundant within the Yorkville granodiorite (see also general discussion of septa under Yorkville Granodiorite).

Some of the quartz-biotite schist septa have sharp contacts with the coarse porphyritic granodiorite but in several instances the contact is made complex by the presence of numerous pegmatite and aplite dikes and quartz-muscovite veins.

Sillimanite-biotite gneiss in septa differs from similar gneiss west of the granodiorite contact in that the former contains more sillimanite, and is coarser grained. Four thin sections have the following estimated modal range:

quartz	35 to 40 per cent
sillimanite	15 to 30 per cent
muscovite	5 to 30 per cent
biotite	5 to 10 per cent
microcline and orthoclase	0 to 40 per cent
oligoclase and myrmekite	0 to 3 per cent

accessory amounts of magnetite, zircon, apatite, tourmaline and a phosphate (?) mineral.

The gneiss is generally medium to dark gray, well foliated and medium grained. Sillimanite occurs as small fibers in thin matts within the plane of foliation or as coarse (1 x 10 millimeters) light gray prisms.

Some of the gneiss that crops out just south of Crowders Creek is folded into a series of very tight small (1 to 2 inch amplitude) folds. The folded layering in this gneiss consists of alternate thin bands of varying composition: pure quartz, quartz-biotite-feldspar, quartz-feldspar. Such intimate interlayering suggests that the parent rock was a thinly laminated silt or mud stone. The quartz and feldspar grains in these bands are fine grained (0.18 to 0.3 millimeters); the quartz shows only slight or moderate undulatory extinction. Most of the coarse grained (1 centimeter) sillimanite prisms lie within the plane of the layering and some are oriented parallel to the axes of the small folds. Some, however, transect the layering and show no preferred orientation with respect to the fold axes indicating that they probably developed after the folding.

Metasomatism in these gneisses is suggested by small quantities of interstitial myrmekite and sodic oligoclase (see Yorkville Granodiorite). Furthermore, a few thin sections indicate that biotite, muscovite, and microcline have been partially replaced by quartz.

Septa of garnet-sillimanite-biotite schist occur at a few places in the Kings Mountain-Henry Knob area. The estimated mode of one of these occurrences is:

quartz	50 per cent
biotite	20 per cent
sillimanite	15 - 20 per cent
garnet	5 - 10 per cent

accessory: muscovite, magnetite, apatite and zircon.

Garnet occurs as coarse subhedral poeciloblastic crystals generally up to 3 millimeters, and locally as much as 3.2 centimeters in diameter.

The texture of the schist is generally porphyroblastic with biotite and fine grained matts of sillimanite defining a strong foliation that wraps around the coarser grained garnets.

Hornblende Gneiss

Distribution and Types

Hornblende gneiss is a common metamorphic rock type in this part of the Piedmont. It occurs in various places in the Kings Mountain-Henry Knob area. Some of the hornblende gneiss in the area represents metamorphosed extrusive rocks of intermediate to basic composition and one large body is metamorphosed quartz gabbro. The parent rocks of the hornblende gneiss are of various ages: metavolcanic hornblende gneiss is interlayered with the oldest biotite gneiss as well as the youngest schistose pyroclastic rock. The quartz gabbro intrudes the oligoclase tonalite but is probably older than the period of deposition of the high alumina rocks. Metamorphism of these parent rocks to hornblende gneiss occurred during the emplacement of the Yorkville granodiorite. Some of the gneiss indicates a degree of metamorphism equivalent to the albite-epidote amphibolite facies (Turner, 1948) but most belongs to the amphibolite facies.

The principal occurrences of hornblende gneiss are: (i) Southeast of Henry Knob where hornblende gneiss underlies an area of about two square miles. This hornblende gneiss is probably continuous with the smaller body immediately north of Henry Knob and the long thin layer in biotite schist northeast of Henry Knob. The parent rock in all three cases was a coarse grained quartz gabbro that locally intrudes the biotite gneiss and oligoclase tonalite. (ii) An area of one half of a square mile immediately south of Trinity Church. The hornblende gneiss here is probably a metavolcanic of intermediate composition. A portion of this metavolcanic rock has been albitized, probably prior to the latest metamorphism, with the result that the present mineral assemblage is quartz-albite-tremolite (and hornblende).

Smaller bodies of hornblende gneiss, also derived from intermediate or basic volcanic rocks, include a long thin layer in biotite schist northwest of Unity Church, a body of unknown size in schistose pyroclastic rock north of The Pinnacle, numerous very small bodies in the main area of biotite gneiss north of Henry Knob, and a few long narrow septa in the Yorkville granodiorite.

Metamorphosed Quartz Gabbro

The least metamorphosed quartz gabbro occurs about one and one half miles southeast of Henry Knob. This rock has the following estimated mode:

hornblende	30 per cent
labradorite, An 50+	55 per cent
quartz	15 per cent

accessory biotite, epidote and magnetite.

Coarse grained hornblende (up to 4 millimeters) and labradorite occur as random interlocking crystals, with quartz in interstitial position. Hornblende is pleochroic from pale brownish green to bluish green. The labradorite crystals are distinctly zoned and albite twinning lamellae are sharp and straight. Hornblende and biotite show minor alteration to chlorite.

Metamorphism of quartz gabbro has resulted in the development of a moderate to strong foliation and a decrease in grain size so that the rock is typically medium to coarse grained. Thin sections of this metamorphosed rock indicate recrystallization of labradorite crystals for the crystals contain numerous fine grained quartz inclusions, and albite twinning is invariably irregular and fuzzy. The anorthite content of the labradorite varies from about An 50 to An 65-70. The random orientation of the coarse grained labradorite crystals, and interstitial position of quartz are characteristic of even the moderately foliated gneiss but in the highly foliated gneiss quartz is more evenly distributed and has a typical granoblastic habit.

Nine thin sections of this hornblende gneiss have the following estimated modal range:

labradorite	40 to 50 per cent
hornblende	15 to 45 per cent
quartz	15 to 35 per cent

accessory epidote, magnetite, apatite and biotite.

Thin dikes of quartz gabbro cut the biotite gneiss and oligoclase tonalite east and northeast of Henry Knob. These dikes are generally 1 to 6 inches wide and have been metamorphosed so that they now consist of dark gray fine grained amphibolite. The principal constituents are labradorite or andesine, An 45, quartz, and hornblende. Some of the hornblende has recrystallized to medium grained porphyroblasts.

The long thin body of hornblende gneiss that occurs interlayered with biotite gneiss northeast of Henry Knob is seen in thin sections to have the relict texture and mineralogy of the quartz gabbro. This long thin body may be a sill or dike in biotite gneiss.

About one and one half miles south of Henry Knob the hornblende gneiss occurs as a belt, 600 to 1,000 feet wide, between quartz-mica schist and Yorkville granodiorite. The gneiss here is highly biotitic; it is locally injected with pegmatite dikes, presumably related to the granodiorite. A characteristic feature of this belt is the presence of occasional veins (and pieces of float) of very hard, tough fine grained epidosite. This rock consists of about 50 to 60 per cent anhedral epidote, 40 to 50 per cent quartz, and small amounts of andesine, hornblende and magnetite. The andesine occurs as small highly irregular grains clustered near the epidote which commonly occurs in massive aggregates. It appears that epidote has almost completely replaced andesine. This rock is probably the hydrothermal alteration product of the metamorphosed quartz gabbro.

Metavolcanic Hornblende Gneiss

The combination of relict porphyritic texture (Figure 4) and mineral composition suggest that the bulk of hornblende gneiss in the large area near Trinity Church, and in various smaller bodies throughout the area, has been derived from volcanic rocks of basic and intermediate composition.

Hornblende gneiss of this type is interlayered with metavolcanic biotite gneiss and, in one case, is gradational with biotite gneiss over a distance of fifty feet. At one locality hornblende gneiss occurs as an apparently conformable layer with conglomeratic biotite schist.

In general, hornblende gneiss of this type displays a well developed foliation, and the fine to medium grained black hornblende prisms commonly define a lineation in the rock. The texture is generally equigranular or blasto-porphyritic (coarser feldspar) but the hornblende gneiss in the septa commonly has coarse grained hornblende porphyroblasts.

The estimated modal range of the metavolcanic gneiss as indicated by six thin sections is:

plagioclase	40 to 60 per cent
hornblende	5 to 60 per cent
quartz	0 to 15 per cent
biotite	0 to 20 per cent (generally less than 5 per cent)

accessory epidote, magnetite, sphene, apatite, zircon and garnet.

In thin sections the hornblende is seen as brownish green and green subhedra and euhedra. Medium to coarse grained (up to 3 millimeters) relict plagioclase phenocrysts with random orientation (Figure 4) constitute a few per cent of the rock in most thin sections. These relict phenocrysts have irregular shapes and invariably exhibit irregular fuzzy twinning. They commonly are embayed by, or hold inclusions of, quartz, epidote, and feldspar. The groundmass consists of very fine to fine grained quartz, feldspar and epidote. The composition of plagioclase in the groundmass and phenocrysts is the same in any one thin section and generally ranges from median oligoclase to medium andesine in rocks from the central part of the area. The plagioclase is albite in hornblende gneiss interlayered with schistose pyroclastic rocks north of The Pinnacle, and in albitized rock near Trinity Church. In hornblende gneiss septa the plagioclase is median to calcic andesine.

In the case of the hornblende gneiss interlayered with schistose pyroclastic rocks, the albite seems to be part of the mineral assemblage, quartz-albite-hornblende-epidote indicating a degree of metamorphism equivalent to the albite-epidote amphibolite facies. With the exception of the albitized rock, the remainder of the hornblende gneiss in the area indicates a degree of metamorphism equivalent to the amphibolite facies.

Albitization

A distinctive white to light greenish gray rock crops out over a distance of 1.3 miles in the area immediately south of Trinity Church. The rock is fine to medium grained and non-foliated. It consists principally of albite and quartz with small amounts of fine grained tremolite and hornblende scattered throughout the rock. Tremolite is also concentrated on slickensided surfaces. Epidote veins are common in the unalbitized hornblende-andesine-gneiss that occurs nearby. The veins have been folded and also show minor offset along small faults. These veins may have developed as CaO and Al_2O_3 were released from the albitized rock. The contact between albitized rock and normal hornblende gneiss was not seen.

In thin sections the albitized rock is seen to consist of about 60 per cent albite, Ab 92, and 30 per cent quartz. Both of these minerals are very fine grained (0.03 to 0.07 millimeters) and comprise an aggregate that appears to have permeated the rock. This aggregate forms anastomosing streams about randomly oriented medium grained relict phenocrysts (now albite), as well as about islands composed of plagioclase phenocrysts and pigeonite. The relict phenocrysts have irregular fuzzy albite twin lamellae, and are embayed at their margins by quartz and albite. Some of the phenocrysts are bent. Pigeonite ($-2V$ small, $c \wedge z = 44^{\circ}$) occurs as irregular ragged grains with a thin margin of chlorite. Small, euhedral pale green hornblende makes up about 5 per cent of the rock in one thin section. Tremolite (5 per cent) occurs in another thin section and seems to have replaced pigeonite. Accessory minerals include epidote, microcline, pyrite, sphene, apatite and garnet.

The mineralogy indicates that the albitized rock contains 72-73 per cent SiO_2, 6 per cent Na_2O and only a trace of K_2O. This composition compares quite well with that of some quartz keratophyres (Gilluly, 1935, p. 235; Turner and Verhoogen, 1951, p. 204).

It is concluded that the original rock was a pigeonite-bearing effusive, probably of intermediate to basic composition. Albitization and silicification were probably produced by hydrothermal solutions from the magma of the soda-rich oligoclase tonalite. The folded and faulted epidote veins in nearby gneiss suggest that albitization occurred prior to the last major deformation and metamorphism in the area. The fine grained euhedral hornblende and tremolite probably developed in the albitized rock during the major metamorphism and perhaps the anorthite content of the albite was not increased much at this time because of the separation of the CaO (epidote veins) from albite.

Septa in Yorkville Granodiorite

Septa of hornblende gneiss occur mainly in the vicinity west of Pisgah Church. They have sharp contacts with the surrounding coarse grained granodiorite.

In general, the texture of this gneiss is porphyroblastic with quartz and andesine (An 42 to An46) forming a very fine to fine grained granoblastic groundmass and hornblende, pleochroic from pale brown to greenish brown, occurring as coarser grained (up to 3 millimeters) porphyroblasts.

The bulk chemical composition, as indicated by the mineralogy of these gneisses, (andesine-hornblende and andesine-hornblende-quartz) suggests that the parent rock was a basalt.

Oligoclase Tonalite*

Introduction

Coarse grained oligoclase tonalite crops out in two northeast-trending elongate bodies on either side, and to the north of Henry Knob. Metamorphism of oligoclase tonalite to biotite gneiss, and the intense weathering of all the rocks in this area make the areal extent and general nature of the oligoclase tonalite contacts uncertain.

Oligoclase tonalite, less metamorphosed than the rock near Henry Knob, occurs immediately north of the north end of Clubb Mountain, Lincoln County, North Carolina. The extent of this rock is not known for no general mapping was done in this area.

The two elongate bodies in the vicinity of Henry Knob occur within a large northeast-trending belt mapped as "Bessemer Granite" by Keith and Sterrett (1931). Oligoclase tonalite is the only granitic textured rock within the tract mapped as "Bessemer Granite" in the Kings Mountain-Henry Knob area. Other rocks in the "Bessemer Granite area" include fine grained biotite schist and gneiss, hornblende gneiss, and quartz-mica schist. Thin dikes of metamorphosed quartz gabbro cut the oligoclase tonalite northeast of Henry Knob.

Northwest of Henry Knob the oligoclase tonalite is characterized in many places by the presence of small and large angular inclusions of biotite schist (Figure 5). Locally, the oligoclase tonalite has been injected into a brecciated zone of biotite schist. These features, in addition to the phenocrystic nature of both quartz and feldspar, offer the most reliable clues to a magmatic origin of the tonalite.

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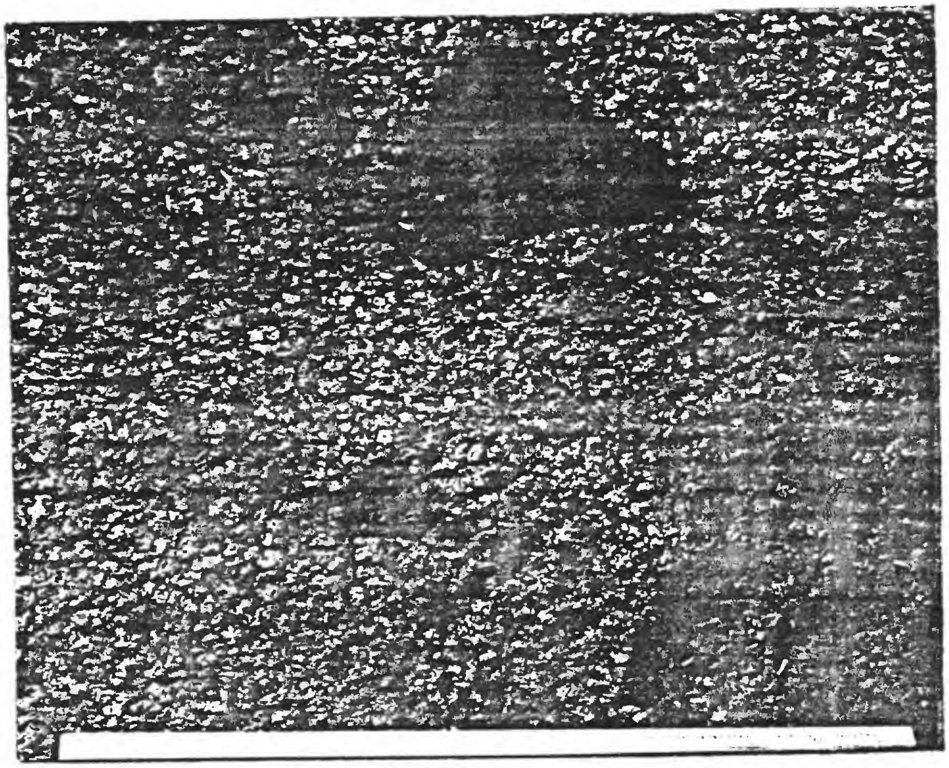
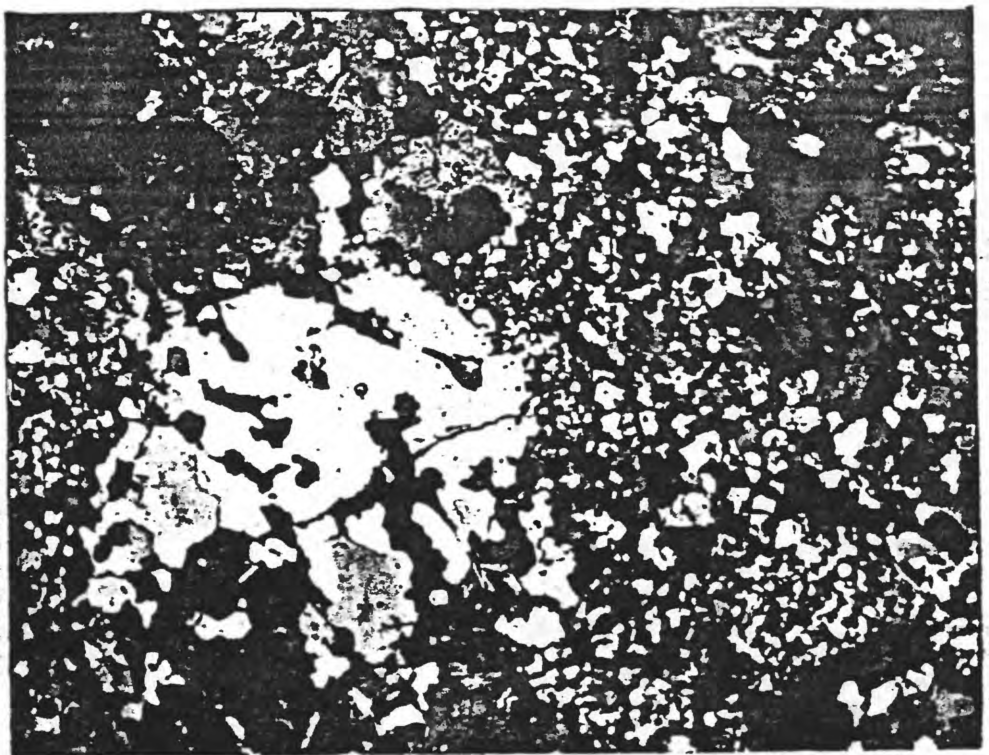
* The rock is a tonalite (228) according to Johannsen (1932, p. 387). The modifier indicates the high content of sodic oligoclase.

Figure 5. Angular inclusions of biotite schist in typical coarse grained oligoclase tonalite. Outcrop in stream bed 1.5 miles N70W of Henry Knob. Scale is one foot long and is graduated in inches and tenths of inches. Photograph by W.C. Overstreet.

Figure 6. Photomicrograph of oligoclase tonalite showing partially recrystallized quartz phenocryst (Q). Note small embayment of sodic oligoclase into quartz phenocryst. Other constituents are: coarse grained partially recrystallized oligoclase (O), fine grained groundmass of quartz and sodic oligoclase, biotite (B). Crossed nicols, X 25.





Description

The coarse grained oligoclase tonalite is typically a light gray rock consisting principally of plagioclase, Ab 80 to Ab 95, quartz and biotite. Biotite occurs as discrete clusters, up to 1 centimeter across, spotted through the light gray quartz and oligoclase. At most outcrops the rock has a massive structure, but occasionally a moderate to strong lineation or foliation is defined by smeared-out biotite clusters and elongate quartz grains. Quartz occurs typically as phenocrysts varying from 1 or 2 to 8 millimeters in length; and as inequigranular grains in a groundmass interstitial to the oligoclase. The quartz phenocrysts are generally somewhat rounded and have the appearance of elliptical pebbles. Plagioclase appears as random light gray to creamy crystals up to 2 to 3 millimeters across.

All plagioclase in a given thin section has the same composition which is generally Ab 80 to Ab 90. The phenocrysts appear as random, more or less anhedral, crystals commonly corroded at the margins and embayed by very fine grained (0.05 to 0.07 millimeters) plagioclase and quartz. Albite twinning is commonly vague or patchy. Overgrowths, embayments and veins of albite, showing very fine shredded twinning lamellae, are common in some thin sections and in these the phenocrysts are also albite.

Microcline occurs in about half of the sections studied. It occurs most abundantly in the least metamorphosed tonalite but even here constitutes only 4 per cent of the thin section. In this thin section it occurs as rather coarse microperthitic anhedra irregularily embayed and veined by sodic oligoclase. In other thin sections microcline is almost completely altered to plagioclase and quartz with the result that only a few small irregularly shaped grains remain. Judging from the size, shape and space relations of the quartz and oligoclase in thin section it is probable that microcline did not constitute more than 10 per cent of the original rock which may have had the composition of a soda-rich granodiorite.

Quartz occurs as large phenocrysts (Figure 6) and as distinct aggregates of grains. The zonal growth of some coarse grained phenocrysts is indicated by the presence within the phenocryst of a series of thin curved layers of albite that are parallel to the margins of the phenocryst. Albite has apparently been introduced into fractures along successive growth zones. Most quartz phenocrysts show varying degrees of recrystallization. Some are entirely rimmed by an aggregate of fine anhedral quartz. This fine anhedralquartz is common throughout most of the thin sections.

Biotite, pleochroic from pale brown to moderate dark brown, occurs as small flakes in distinct clusters. Some of the biotite has been altered to chlorite. The euhedral outline of a chlorite aggregate in one thin section suggests that chlorite has replaced amphibole pseudomorphically.

Muscovite occurs as small distinct flakes intergrown with biotite in many thin sections. It also occurs as fine grained flakes in some of the fine grained quartz aggregates.

Accessory minerals include epidote, magnetite, apatite, pyrite, sphene, rutile, zircon, garnet, staurolite, and kyanite.

The average of eight modal analyses of typical coarse grained light gray oligoclase tonalite is given in Column 4 of Table III. The mode and chemical composition (Column 1, Table III) agree closely with the quartz-oligoclase tonalite (trondhjemite), 228P, and soda-clase tonalite, 218P , of Johannsen (1939, p. 387, 383). The bulk chemistry and mineralogy of the oligoclase tonalite also resembles trondhjemite from the Sierra Nevada, California (Heitanen, 1951, p. 584) which has intruded a metamorphosed igneous complex consisting of basaltic and soda-rich volcanic rocks.

Alteration and Metamorphism

A few of the alterations seen in thin section may be definitely attributed to deuteric alteration, some are distinctly metamorphic and others may be either of metamorphic or late magmatic origin.

The oligoclase phenocrysts are generally crowded with randomly oriented fine grained mica. This mica is commonly more abundant in the cores than in the margins of the grains and is completely lacking from the overgrowths and fine grained embayments. This mica is believed to be of deuteric origin.

Thin section study reveals that there has been an introduction of albite and quartz into the rock. What is the extent of this alteration and when did it occur? An approximate measure of the extent is suggested by a comparison of the mode and chemical analysis of the oligoclase tonalite with five examples of trondhjemite cited by Johannsen (1932, p. 387). The oligoclase tonalite contains as much as 10 per cent more quartz, and has a higher $Na_2O:K_2O$ ratio than most trondhjemites. These comparisons suggest a slight to moderate amount of silicification and albitization of the oligoclase tonalite and this agrees with thin section evidence.

TABLE III

Chemical and modal analyses of oligoclase tonalite

	1.	2.	3.		4.	
SiO_2	73.89	71.57	Sodic Oligoclase and albite	59.9	Sodic oligoclase and albite	53.6
Al_2O_3	14.45	15.78	Quartz	28.1	Quartz	35.1
Fe_2O_3	.56		Biotite	8.1	Microcline(0-4.2)	1.0
FeO	1.22		Chlorite	0.5	Biotite	6.4
MgO	.94	1.11	Muscovite	3.3	Chlorite(0.0-1.8)	.7
CaO	1.33	1.42	Magnetite	0.1	Muscovite	2.5
Na_2O	5.56	6.10			Epidote(0-2.2)	
K_2O	1.04	1.37			Magnetite (0-0.6)	
H_2O-	.04				Pyrite (0-0.2)	
H_2O+	.61	.59				
TiO_2	.28					
CO_2	.01					
P_2O_5	.05					
MnO	.04					
	100.02	100.45				

1. Chemical analysis of typical coarse grained oligoclase tonalite from stream bed 1.85 miles N39E of the crest of Henry Knob. Sample was a composite of small chips and chunks from one outcrop. Analyst: Lucille N. Tarrant, U.S. Geological Survey.
2. Chemical composition calculated from mode, column 3.
3. Mode of typical coarse grained oligoclase tonalite. Average of two thin sections from samples used for chemical analysis in column 1 ; 1000 points counted in each thin section.
4. Mode of typical coarse grained oligoclase tonalite. Average of two thin sections (including two in column 3). Seven thin sections of oligoclase tonalite in area north of Henry Knob, South Carolina. One thin section from float ½ mile north of the north end of Clubb Mountain, Lincoln Co., North Carolina.

The overgrowths, and veins and embayments of plagioclase and quartz into phenocrysts suggests hydrothermal or late magmatic alteration rather than an alteration produced by dynamothermal metamorphism. It is concluded, therefore, that albitization and silicification occurred shortly after the oligoclase tonalite crystallized, perhaps as part of the same igneous episode. The albitization seen in biotite gneiss and in hornblende gneiss also probably occurred at this time.

Metamorphism, subsequent to albitization and silicification of oligoclase tonalite, brought about the equalization of plagioclase grain size and equalization of plagiclase composition in the rock. Quartz phenocrysts exhibit very nicely the first stages of recrystallization: a single euhedral phenocryst breaks down to a mosaic of small strained grains but the aggregate retains the euhedral outline of the phenocryst, (Figure 6). More advanced stages of recrystallization show the distortion of the euhedral outline and the enlargement of some of the small grains in the mosaic. Some short stringers and lenses of slightly strained quartz grains may represent highly recrystallized phenocrysts.

The final product of recrystallization is a strongly foliated biotite gneiss (see Biotite Schist and Gneiss).

Another common alteration product of oligoclase tonalite is thinly foliated pyritic quartz-mica schist (see separate discussion).

Quartz-Mica* Schist

Highly foliated very fine grained to medium grained quartz-mica schist is the rock type next most abundant to biotite schist and gneiss in the area. Because quartz-mica schist has various origins the areas mapped (Plate I) do not, in general, fit into any broad or local structural pattern. Thus, in some places, as in the long narrow belts in the vicinity of Sparrow Springs Lake and south of Henry Knob, quartz-mica schist is probably a metasedimentary or metavolcanic unit, whereas in the area north of Henry Knob the schist has been produced by intense local shearing and alteration of biotite schists, gneisses and coarse grained oligoclase tonalite.

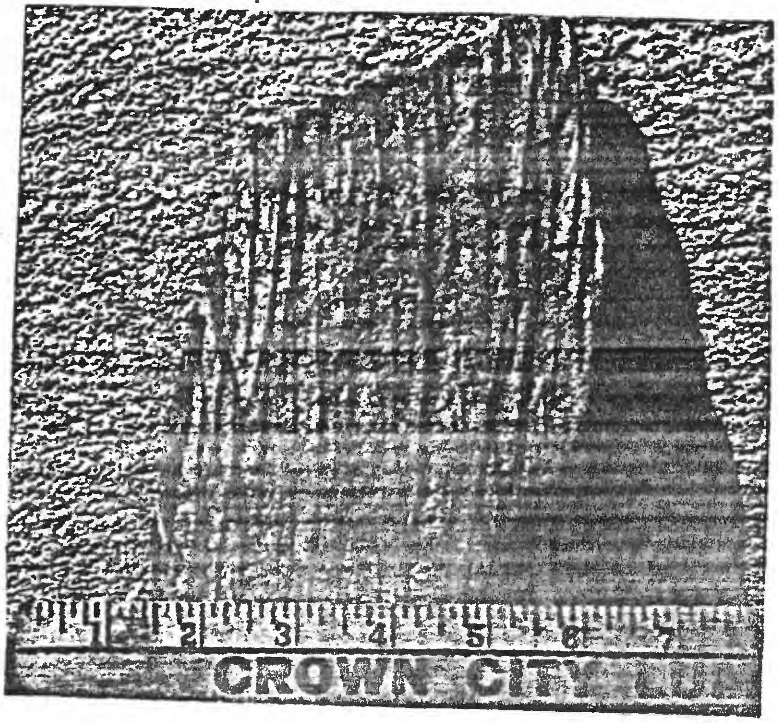
Some of the least metmorphosed metasedimentary schist occurs in the narrow belt extending northeast through Sparrow Springs Lake. The schist here is very fine grained and the strongly developed cleavage is commonly crinkled. Fine grained needles of tourmaline occur on the foliation planes. This schist varies from white and gray to bluish gray in color. It is interlayered with bluish gray phyllitic schists in this belt. Although no thin sections of this rock were studied, the principal constituents were seen in the field to be fine grained mica and quartz with accessory amounts of magnetite, pyrite, and tourmaline. The composition of the mica is unknown but it is probable that it contains considerable amounts of Na_2O as well as K_2O (see Chloritoid Schists).

In the vicinity of the sillimanite quartzite beds near the Yorkville granodiorite contact, the schist is generally well foliated and frequently highly crenulated (Figure 7) and folded. It consists principally of quartz and well formed mica with small and variable

* All white mica, unless inferred from chemical analysis or optical data to be muscovite, is referred to as "mica". (See discussion under Chloritoid Schists).

Figure 7. Hand specimen of crinkled quartz-mica schist. The well developed flow cleavage in the schist is parallel to the plane of the photograph. Specimen from gas pipe line south of Will Knox property. Scale is graduated in inches.

Figure 8. Thin bedded schistose pyroclastic rock. Looking down on gently dipping beds in road gutter one-half mile north of Sparrow Springs Lake. Note fragments in coarse grained bed that are flattened and elongated in plane of steeply dipping foliation. Scale is one foot long. Photograph by W.C. Overstreet.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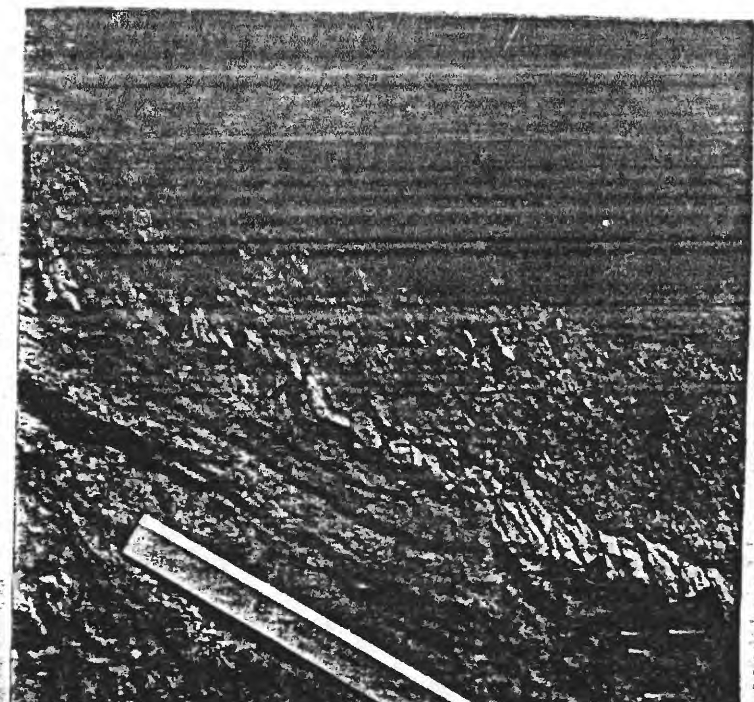


amounts of sillimanite, garnet, rutile, zircon, tourmaline, and, locally, andalusite (Will Knox property). It is locally conglomeratic.

Just north of the folded kyanite and sillimanite quartzite beds in the vicinity of McGill Creek there appear a few scattered exposures of mottled bluish fine grained schist that resembles the schistose pyroclastic rocks. These exposures occur in an area of quartz-mica schist suggesting that the quartz-mica schist has developed by shearing and alteration of the schistose pyroclastic rocks. Indeed, the bulk of the strongly foliated quartz-mica schists associated with the sillimanite quartzite beds may be the highly metamorphosed equivalent of the fine grained chloritoid schists, quartz-mica schists and schistose pyroclastic rocks associated with the kyanite quartzite on the west limb of the major anticline (I, Figure 2).

The high alumina content of the quartz-mica schist associated with kyanite quartzite is indicated by some of the minerals recovered by panning weathered schist in the immediate vicinity of the quartzite. Staurolite, kyanite, tourmaline and magnetite were recovered from the schist near kyanite quartzite one half mile southeast of the south end of Crowders Mountain. Within 200 feet of kyanite quartzite at Henry Knob, the following minerals occur in the quartz-mica schist: kyanite, staurolite, andalusite (local), tourmaline, pyrite, rutile and magnetite. Pyrite is generally a widespread accessory mineral in the schist.

One thin section of quartz-mica schist from an outcrop 1 mile south of Henry Knob shows the presence of a few highly altered feldspar crystals (1 to 2 millimeters) in a very fine grained groundmass of quartz, mica and chlorite. Some of the coarser quartz grains have the appearance of relict phenocrysts. Pyrite constitutes 1 to 2 per cent of the rock and occurs as crystals elongated in the plane of foliation. It is likely that this schist was derived from a silicic volcanic rock.

Pyritic quartz-mica schist, developed by shearing and hydrothermal alteration of pre-existing biotite schist, gneiss and oligoclase tonalite, is common in the general vicinity north and southeast of Henry Knob. This schist is strongly foliated and occurs in zones from about 2 feet to 20 feet wide. The contact between these zones and oligoclase tonalite is usually sharp. Gently plunging slickensides on steeply dipping foliation planes in the schist, and intense local crumpling, attest to the shearing nature of the deformation that accompanied alteration of tonalite to schist. Some hydrothermal action is suggested by small veins of quartz and tourmaline that cut the tonalite near the schist.

At one locality northeast of Henry Knob the schist has a distinctly pebbly character produced by numerous quartz eyes. The unaltered tonalite adjacent to the schists contains abundant rounded quartz phenocrysts, suggesting that quartz eyes in the schist are relict phenocrysts.

The hydrothermal alteration recorded by these schists and the small quartz-tourmaline veins may have been largely a hydrolysis of the plagioclase in the oligoclase tonalite. The general reaction, is assumed to have been:

$$\underset{\text{albite}}{3\ NaAlSi_3O_8} + H_2O \rightarrow \underset{\text{paragonite}}{NaAl_3Si_3O_{10}(OH)_2} + Na_2O + 6\ SiO_2$$

Although the plagioclase in the oligoclase tonalite is not pure albite, it is highly sodic and thus paragonite, and not potash mica, would have formed. There is, however, no chemical or petrographic evidence to indicate the composition of the mica. The release of Na_2O and SiO_2

by this reaction may explain some of the local albitization and silicification. However, there appears to be no correlation between albitized tonalite and the proximity of this tonalite to zones of schist. Nor is there an obvious spatial correlation between the well defined albitization of rocks south of Trinity Church and zones of quartz-mica schist. It is concluded that little, if any, albitization resulted from the Na_2O released by this reaction.

Schistose Pyroclastic Rock

Introduction

Fine grained mica schist, having a distinct relict fragmental texture and a bluish gray and mottled bluish and white color, crops out in a broad belt one mile southeast of the Kings Mountain ridge (Plate I). Associated with the pyroclastic rocks in this belt are magnetiferous quartzite, very fine grained light tan and green colored schist (probably tuffaceous) and schistose porphyritic volcanic rocks of silicic to intermediate composition.

Another belt of this schist occurs at the axis of the syncline (II, Figure 2) north of The Pinnacle. Metavolcanic hornblende gneiss occurs with the schist in this belt. Both kyanite and andalusite occur locally in this schist.

Small outcrops of schistose pyroclastic rock occur elsewhere in the area and are always close to, or in contact with, the kyanite-bearing quartzites. Thus, a small outcrop of schistose pyroclastic rock occurs along the road just west of Sherrars Gap; much of the schist exposed along the east side of Crowders Mountain has the color and textural characteristics of this rock; two small outcrops of this schist occur in McGill Creek, just north of the kyanite and sillimanite quartzite beds. A schist of similar appearance, but containing abundant sillimanite, crops out along the west side of a small hill (Ryan-Purcley property) 2.7 miles northeast of Henry Knob.

It is difficult to assess the grade of metamorphism from the mineral assemblage of the schistose pyroclastic rock because the rock consists dominantly of quartz and mica, an assemblage stable over a wide range of temperatures. Rocks belonging to the greenschist facies

(Turner, 1948) are associated with the schistose pyroclastic rock in the vicinity of Oak View Baptist Church; north of The Pinnacle the associated rocks belong to the albite-epidote amphibolite facies and here the schistose pyroclastic rock carries andalusite and kyanite; the sillimanite-bearing schistose pyroclastic rock in the eastern part of the area is surrounded by rocks of the amphibolite facies.

Keith and Sterrett (1931) mapped much of this schistose pyroclastic rock, along with other fine grained quartz-mica schists cropping out along the Kings Mountain range, as Battleground schist. The type locality is at the Kings Mountain Battleground, 6 miles southwest of The Pinnacle. Keith and Sterrett conclude that the Battleground schist is of Algonkian age, but the present study indicates that these distinctive pyroclastic rocks lie stratigraphically below and above the Kings Mountain quartzite (kyanite quartzite and conglomerate) which they consider to be of Cambrian age (see Structure).

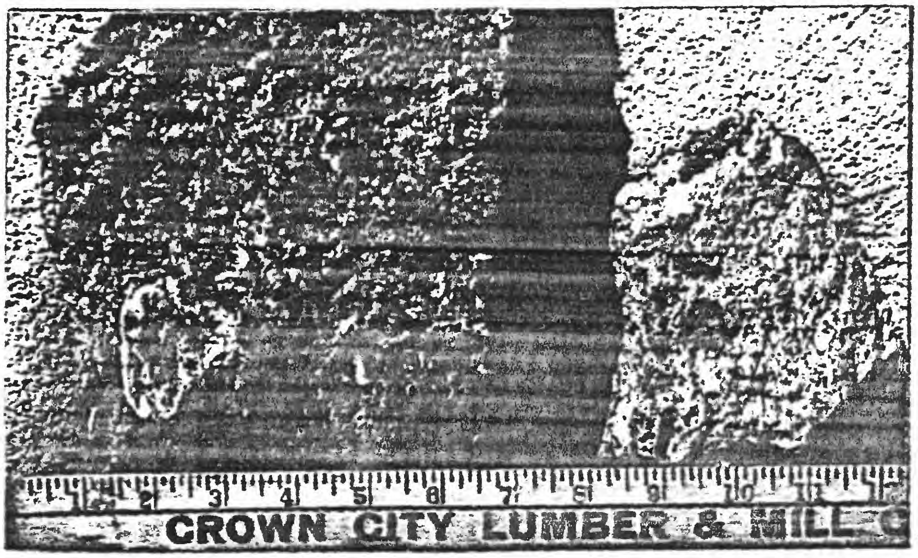
Description

The schistose pyroclastic rock has been strongly sheared with the result that the pyroclastic fragments are usually highly flattened and elongated. Bedding, however, is generally well preserved (Figure 8). Some beds are very fine grained and consist predominantly of fine grained quartz and mica while others are coarser grained and contain the characteristic angular fragments.

The groundmass in these coarser grained beds consists now of fine grained mica, quartz, and hematite, with occasional clear bluish quartz grains (2 to 3 millimeters) having sharp outlines suggesting phenocrysts. Imbedded in this groundmass are angular fragments (now entirely schistose) of varying color and size, (Figure 9). Some of these

Figure 9. Two hand specimens of schistose pyroclastic rock from gas pipe line 1.15 miles S15E of Sharrars Gap. Specimen on right shows angular fragments of dark colored porphyritic rock set in groundmass of fine grained mica and quartz. Specimen on left consists of light and dark colored fragments that have been sheared and flattened; foliation plane is parallel to plane of photograph. Scale is graduated in inches.

Figure 10. Outcrop of pebble conglomerate 0.45 miles N75E of Oak View Baptist Church. Looking down on outcrop which shows flattened and elongated pebbles of quartz-hematite schist in groundmass of fine grained quartz and mica. Scale is one foot long. Photography by W.C. Overstreet.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fragments are 2 inches long, but generally they are between one fourth and one inch long. They consist of fine grained mica and a little quartz, and depending on the amount and distribution of hematite, appear white, gray, bluish gray or black. Finely disseminated hematite gives these fragments and the matrix the distinctive gray color. A few angular fragments have relict porphyritic textures. These fragments resemble closely the porphyritic volcanic rocks associated with the pyroclastic rocks and described below.

One outcrop of pyroclastic rock, one half mile east of Oak View Baptist Church, consists in addition to well defined beds containing angular fragments, of a conglomeratic layer containing large pebbles and cobbles (Figure 10). These cobbles and pebbles are well rounded and are highly flattened and elongated in the plane of foliation. The ratio of their maximum length to width is about 5:1. They consist of very fine grained dark gray quartz-hematite schist. A curious feature, perhaps inherent in an area where shear folding is prevalent, is that small, angular fragments occur in the outcrop a few feet from these strongly deformed pebbles. The presence of these well rounded pebbles, in addition to the widespread occurrence of small quartzite pebbles in the pyroclastic rock, suggests a composite origin for the clastic material.

Thin sections of the pyroclastic rock reveal little of the original composition. The major constituents are very fine grained (0.01 to 0.03 millimeter) mica, quartz, and hematite. Accessory minerals are tourmaline, apatite, and chloritoid. The mode, calculated from chemical composition and supported by thin section evidence, is given in Table IV.

The fragments are seen in thin section to be distinct areas with angular outlines and consisting of a very fine grained (less than .01 millimeter) micaceous aggregate. Several fragments contain abundant fine grained disseminated hematite. In addition to very fine grained quartz and mica, the groundmass contains rare very fine grained quartzite pebbles and small single grains of quartz that have quite regular outlines suggesting they were phenocrysts. Some of the fine grained masses of mica may have been feldspar crystals.

The hematite appears as fine grained (up to one millimeter) ball-like anhedra, as very fine grained anhedra in distinct bands and trains, and as abundant fine and coarse grains disseminated in some of the fragments. The hematite is distinctly magnetic but the chemical analysis of the pyroclastic rock (Table IV) indicates the iron to be predominantly Fe_2O_3.

If, in the pyroclastic rock, all the soda (2.61 per cent) is considered to be present as paragonite, and all the potash (1.62 per cent) as muscovite, there remains an excess of 1.27 per cent Al_2O_3 and 1.26 per cent H_2O. The mica may well be a single species containing both Na_2O and K_2O and perhaps more water than indicated in the conventional formulas. There is also a possibility that small amounts of pyrophyllite are present.

The alumina content (19.44 per cent) is about 3 to 5 per cent higher than in tuffs with comparable silica content (Washington, 1917). Some of the metamorphosed tuffs of the volcanic-slate belt (Laney, 1910; Pogue, 1910) contain up to 20 per cent Al_2O_3 but, unlike the pyroclastic rock in the Kings Mountain-Henry Knob area, contain less than 60 per cent SiO_2 and as much as 6 per cent CaO. These comparisons suggest that

TABLE IV

Chemical analysis and calculated mineral percentages of schistose pyroclastic rock from Gaston County, North Carolina.

1.		2.	
SiO_2	66.14	Per cent by Volume	
Al_2O_3	19.44	Quartz	49
Fe_2O_3	5.88	Total Mica	47
FeO	.45	Titaniferous	
MgO	.22	Hematite	4
CaO	.29	Tourmaline	Trace
Na_2O	2.61	Apatite	Trace
K_2O	1.62	Chloritoid	Trace
H_2O-	.09		100
H_2O+	2.33		
TiO_2	.64		
CO_2	.01		
P_2O_5	.14		
S	.00		
MnO	.01		
Total			

1. Chemical analysis of schistose pyroclastic rock found along pipe line 1 mile S58E of Stepps Gap, Gaston County, North Carolina. Sample is a composite of six specimens taken at random from excavated rocks. Analyst: Lucille N. Tarrant, U.S. Geological Survey.

2. Volume per centages of minerals calculated from chemical analysis. Mineralogy indicated by thin section study.

the high alumina content of the schistose pyroclastic rock may have resulted from the admixture of some clay with the pyroclastic debris during sedimentation. The fact that andalusite, kyanite, and sillimanite occur in the schistose pyroclastic rock only in the immediate vicinity of the high alumina quartzite can be interpreted to indicate a rather abrupt sedimentary gradation from clay-rich sands (high alumina quartzites) to a clay-bearing pyroclastic sediment. High alumina quartzites occur at both the upper and lower contacts of schistose pyroclastic sequences.

Andalusite-Bearing Pyroclastic Rock

This rock is best developed just west of the kyanite quartzite bed in the trough of the syncline south of Crowders Mountain Village, and just east of the kyanite quartzite beds of Crowders Mountain. In addition to the characteristic mottled colors and fragmental texture, the schist has a lumpy surface produced by the random, coarse grained (one-quarter to one-half inch) andalusite porphyroblasts.

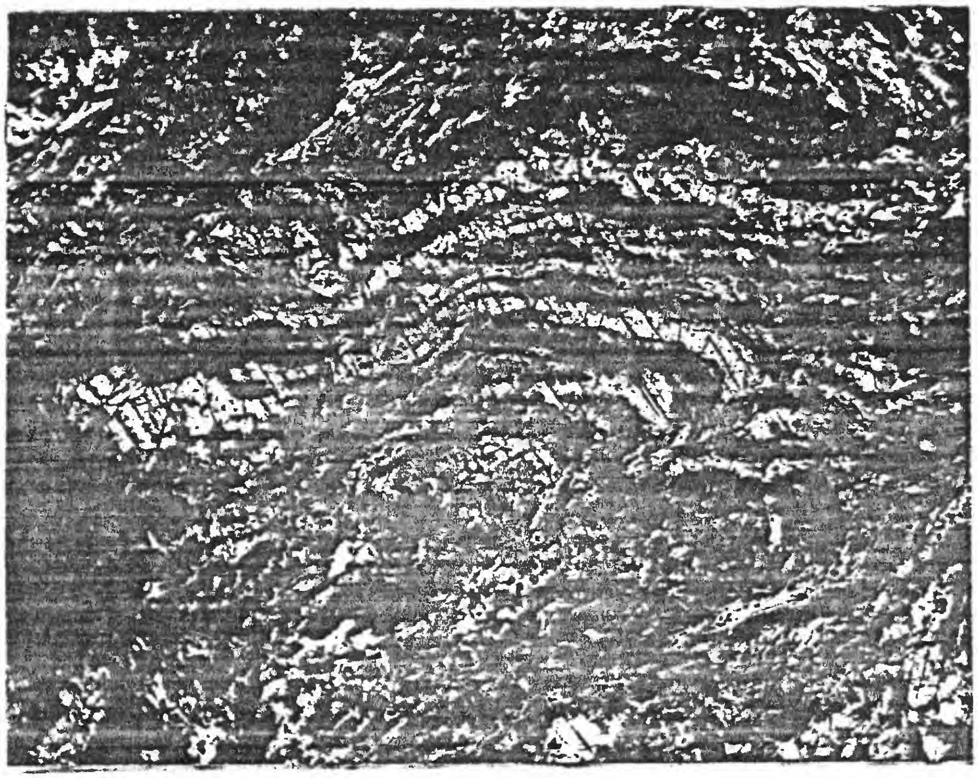
In thin section the schist is seen to consist of about 80 to 90 per cent fine grained mica. The remainder of the rock consists of quartz, magnetite (locally up to 10 per cent), andalusite (trace to 5 per cent), tourmaline (trace to 3 per cent).

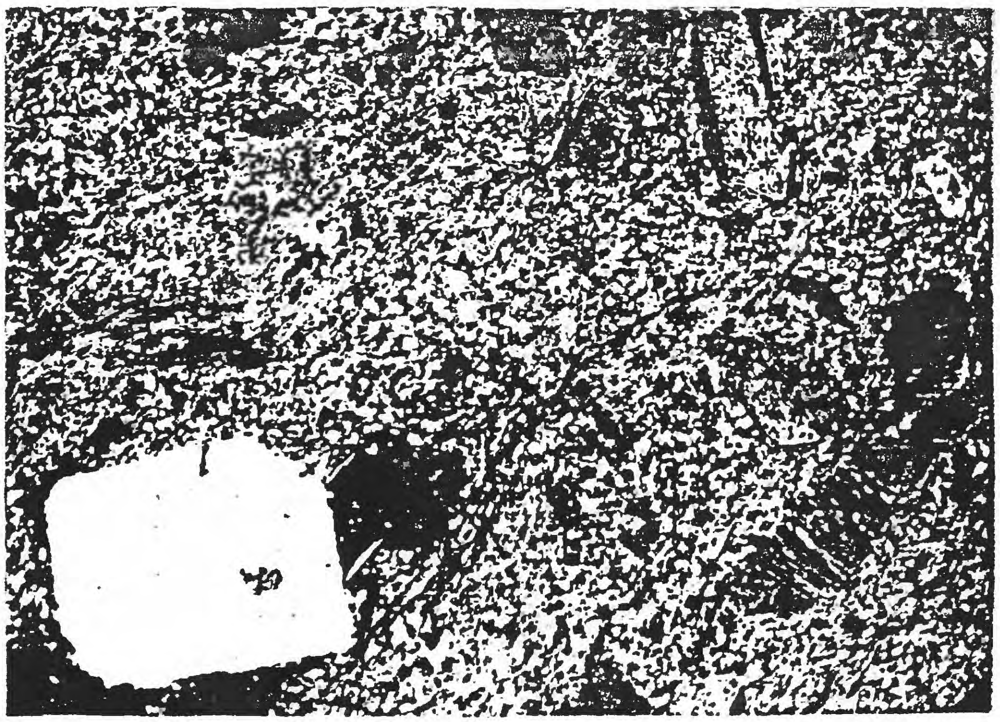
Folded banding is seen in many thin sections. The bands consist of parallel layers rich in fine grained euhedral and anhedral magnetite; others are rich in well-formed flakes of mica that are oriented parallel to the axial planes of the folds; tourmaline-rich bands are common in a few thin sections.

The coarse grained porphyroblasts of andalusite apparently developed after the stage of crumpling for they occur at the noses of folds

Figure 11. Photomicrograph of partially replaced andalusite porphyroblast in schist. Sample from outcrop along road 0.4 mile south of Crowders Mountain Village. Andalusite (well developed cleavage, light gray) has been partially replaced by mica (light colored fuzzy aggregate) and tourmaline (fine grained, dark colored in bands); coarse grained opaque mineral is magnetite. Crossed nicols X 65.

Figure 12. Photomicrograph of metavolcanic albite-chlorite schist. Sample from gas pipe line 1200 feet west of North Carolina highway 161. Large quartz phenocryst in lower left corner; other phenocrysts are albite. Groundmass is quartz, albite and chlorite. Crossed nicols, X 25.





and include crumpled bands of magnetite. Partial replacement of andalusite by mica and tourmaline has taken place along these relict bands within the porphyroblast. This is shown by the isolated remnants of andalusite that have the shape of curved bands (Figure 11). In such cases the isolated remnants have a common optic orientation showing that they were once part of one large crystal.

Kyanite-Bearing Pyroclastic Rock

This rock is common in the vicinity of the northeastern end of Kings Mountain. Here it occurs interbedded with kyanite conglomerate, and is apparently gradational along strike with kyanite-staurolite quartzite.

Kyanite, making up less than 10 per cent of the schist, occurs as complete radial sprays up to 5 millimeters in diameter and as individual blades and irregular aggregates. The schist has the characteristic mottled colors and fragmental texture, and consists principally of fine grained mica, a little quartz, and accessory amounts of chloritoid, magnetite, tourmaline and zircon.

Associated Metavolcanic Rocks

Metamorphosed porphyritic volcanic rocks and extremely fine grained tuffs (?) are associated with the schistose pyroclastic rocks southeast of Kings Mountain.

One of the most distinctive porphyritic rocks, although not widespread, is a fine grained medium gray moderately schistose rock with randomly oriented white feldspar phenocrysts (1 to 2 millimeters) and bluish quartz phenocrysts. Biotite or chlorite occur along the foliation planes. In thin section (Figure 12) the plagioclase phenocrysts are seen to consist now of albite An 5-10, and sometimes to have well preserved crystal outlines; some quartz phenocrysts (up to 1.5 millimeters) are undeformed; the groundmass consists of very fine grained mica, chlorite, quartz, epidote and magnetite. Coarse mica, sometimes ragged and corroded, and chlorite or biotite, occur as coalescing and branching streams that wrap around the phenocrysts and define a moderately good foliation. This schist belongs to the greenschist facies.

It is interesting to note that a porphyritic volcanic rock of similar composition and texture crops out in the center of the belt mapped as Bessemer granite by Keith and Sterrett (1931); the rock was found in a quarry 2.4 miles S 32 E of the Kings Mountain Battleground Monument.

Another metavolcanic type consists of about 85 per cent medium grained albite, An 5-10, crystals with random orientation, a few potash feldspar phenocrysts, and a groundmass of fine grained albite laths, chlorite, mica, and minor quartz. The absence of epidote suggests that the parent rock consisted dominantly of sodic plagioclase. It may have had a composition closely akin to the sodaclase tonalite which is thought to be the parent rock of some biotite gneiss.

Very fine grained, hard, bluish-gray rock occurs at several places along the pipeline southeast of Stepps gap. A thin section of this rock shows it to consist of extremely fine grained (0.008 millimeter) quartz and albitic plagioclase, and coarser grained quartz and mica. The extremely fine grained quartz-albite aggregate occurs as streaks or bands with thin streaks of coarser (.18 millimeter) quartz. This rock may be a metamorphosed volcanic ash.

The hornblende gneiss associated with schistose pyroclastic rocks north of The Pinnacle displays relict porphyritic texture in thin section, (see Hornblende Gneiss).

Chloritoid Schist and Associated Rocks

Introduction

Fine grained clastic metasedimentary rocks, high in quartz and alumina, crop out in two broad belts in the northwestern part of the Kings Mountain-Henry Knob area (Plate I). The principal rock types in these two belts are chloritoid schist, quartz-mica schist, fine grained quartzite, schistose conglomerate and chlorite-albite schist. These rocks lie, for the most part, stratigraphically beneath the kyanite quartzite and conglomerate in the syncline (II, Figure 2); the chloritoid schists southeast of Kings Mountain lie stratigraphically above the schistose pyroclastic rocks. Each of the two belts of chloritoid schist varies from about 1,000 to 4,000 feet in width. Intense small scale isoclinal folding is common in both belts and it is probable that the true thickness of the rocks in either belt is one half to one fourth of the maximum width of the belt. Rocks of this type are also exposed between The Pinnacle and the southwestern nose of the syncline (II, Figure 2) and these lie stratigraphically above the kyanite quartzite beds.

Keith and Sterrett (1931) mapped these fine grained chloritoid schists and quartzites, along with the distinctly pyroclastic rocks, as Battleground schist. In the present study an attempt was made in the field to distinguish the schistose pyroclastic rocks from these fine grained schists. In many cases they seem to be gradational but the distinctive textural features of the pyroclastic rocks, and the presence of a well defined schistose conglomerate bed at the base of the fine grained schists along the west side of Lake Montonia and Yellow Ridge make the contact fairly definite. The fine grained schists and quartzites were largely water-lain fine grained clastic sedimentary rocks. However, a few volcanic types are represented in this sequence, and, indeed, a narrow band of pyroclastic rocks occurs in the fine grained schists east of Sherrars Gap.

The composition of the white mica that constitutes a large part of these fine grained schists is not certain. One clue as to its composition is given by a chemical analyses of "Sericite schist" collected by D. B. Sterrett (Wells, 1937). The rock sample was taken from a point one half mile N40E of Stepps Gap and although no more detailed location is given, it was probably obtained from a point just south of the coarse grained conglomerate at the nose of the fold on the Warren property. The analysis follows:

SiO_2	45.47
Al_2O_3	38.09
Fe_2O_3	2.50
FeO	——
MgO	.21
CaO	.75
Na_2O	4.83
K_2O	4.63
H_2O	4.79
	101.27

The analysis indicates the high alumina nature of the rocks surrounding the conglomerate, and it also indicates that the mica is not "sericite" or muscovite. It may be that the schist consists of an intergrowth of paragonite and muscovite, or, that the mica may be equally rich in soda and potash. Chemical analysis of the fine grained schistose pyroclastic rock (Table IV) indicates that Na_2O is about one and one half times more abundant than K_2O, and this rock consists principally of fine grained mica and quartz. Hence, all fine grained white mica in the area is referred to as "mica", indicating that it may be either muscovite and paragonite or a mica containing both Na_2O and K_2O.

Chloritoid Schist

The most abundant type of schist in both belts is a porphyroblastic chloritoid-chlorite-mica schist. It is particularly well exposed near the kyanite quartzite beds in the southern part of the syncline, at Stepps Gap, and in the vicinity of Lake Montonio and along Yellow Ridge. The schist is tan, gray or bluish gray colored. It is commonly strongly foliated and the foliation planes are generally tightly crinkled. The axes of these crinkles are horizontal or plunge gently northeast or southwest. Intense small scale isoclinal folding of this schist is conspicuous at Stepps Gap and east of Sherrars Gap. A distinct layering is produced in some cases by thin (one half to 10 millimeters) bands alternately rich in chloritoid, chlorite-quartz and mica-chlorite-quartz.

In thin section, chloritoid schist is seen to consist principally of fine grained mica (30 to 90 per cent) and quartz (5 to 70 per cent). The mica flakes generally define a strong foliation. Quartz occurs as a mosaic of very fine (0.01 to 0.09 millimeter) grains interspersed with mica and chlorite, or as fine, randomly oriented, angular grains in a micaceous groundmass. A few small fragments, or pebbles, of quartzite were seen in some thin sections.

Chloritoid constitutes about 3 to 10 per cent of most of the schists. It is more abundant near the kyanite quartzites and here constitutes up to 30 per cent of the schist. It occurs as single blades or radiating bladed aggregates. Single blades are generally 0.1 to 0.5 millimeter long. Radiating bladed aggregates are coarser (up to 2 millimeters) and are particularly well developed in the vicinity of the kyanite quartzite. The color and pleochroism of chloritoid are variable from one thin section to another. Much of the chloritoid is colorless; some is pleochroic from greenish-gray to green. In two sections it is pleochroic from pale green to purplish, suggesting a manganiferous variety. Inclusions of quartz and fine opaque material are common in the chloritoid. In many cases an S pattern of inclusion trains suggests rotation during crystallization. The foliation is commonly bowed about coarse radial aggregates of chloritoid. Chloritoid is seen in some thin sections to be altering to mica and chlorite.

Chlorite is present in 10 out of the 15 thin sections studied. It occurs as small, generally well formed flakes. It is somewhat coarser grained than the mica and is in intimate contact with chloritoid. In several thin sections from both belts chloritoid shows slight to moderate alteration to chlorite. Magnetite, tourmaline, rutile, and zircon are common accessories. Magnetite octahedra commonly show signs of smearing and the ragged nature of some of the octahedra suggests they have been partly recrystallized. Rare accessories are epidote, garnet and biotite. Garnet occurs as small clear anhedra, partially altered to chlorite. Epidote occurs as small ragged anhedra. Biotite occurs in one thin section. It appears to be intergrown with mica; no chlorite occurs in this thin section.

The fine grained clastic nature of much of the quartz in this schist, the abundance of high alumina minerals such as mica and chloritoid, and the presence of delicate banding, defined by compositional variations, suggest that the parent rock was a silty clay comparable in composition to some impure refractory clays (Greaves-Walker, 1939).

The mineral assemblages chloritoid-mica-quartz and chloritoid-mica-garnet indicate a degree of metamorphism equivalent to the green-schist and albite-epidote amphibolite facies respectively (Turner, 1938, p. 89). The random and minor alteration of chloritoid and garnet to chlorite and mica indicates a somewhat later retrogressive metamorphism.

Quartz-Mica Schist

Very fine grained light brown, gray or bluish gray schist, consisting dominantly of quartz and mica, is common in both major belts and also in the trough of the southern part of the syncline. This rock is gradational with the fine grained quartzites described below, and with the chloritoid schists.

In addition to fine grained (0.03 to 0.02 millimeter) quartz and mica, the rock carries accessory or major amounts of magnetite and iron ore of uncertain species. Other accessory minerals are tourmaline and zircon. In most cases the magnetite occurs as disseminated small octahedra. These are sometimes corroded and ragged, suggesting recrystallization. In other samples of this schist the iron ore consists of fine grained ragged ball-like grains, and of very fine anhedra defining bands and inclusion trains in the groundmass. This iron ore looks very similar to that in the schistose pyroclastic rocks where chemical analysis indicates it to be hematite. The iron ore in the schists under discussion also occurs locally disseminated in, and as a narrow coating or rim about small, fine grained quartzite pebbles. The intimate association of fine grained quartz and iron ore suggests that these "pebbles" were ferruginous chert, or perhaps a fine grained crystalline quartz pebble with a coating of iron oxide.

Fine Grained Quartzite

Fine grained quartzite occurs at numerous localities in the two major belts but it is not as common as the highly quartzose chloritoid schists and chloritic schists which Keith and Sterrett (1931) mapped as the Kings Mountain quartzite.

The rock is of variable color depending on the magnetite content and degree of limonitization. It occurs as beds a few inches to a few feet thick, interlayered with chloritoid schist and quartz-mica schist.

In thin section it is seen to consist of a mosaic of very fine grained (0.03 to 0.18 millimeter) quartz. Quartz constitutes from about 70 to 98 per cent of the rock. Other constituents are fine grained mica, magnetite, chlorite, zircon, and tourmaline.

Schistose Conglomerate

Bluish gray schist with coarse pebbles of white quartzite is commonly interbedded with kyanite quartzite along Kings Mountain, southeast of The Pinnacle. In several places kyanite conglomerate is gradational along strike to schistose conglomerate.

A persistent bed of conglomerate can be traced almost continuously for three and one half miles from the west side of Lake Montonio northeast along the west side of Yellow Ridge to Crowders Creek.

This bed was mapped by Keith and Sterrett (1931) as Draytonville conglomerate, as was the kyanite quartzite and conglomerate of the Kings Mountain ridge. The present study suggests that this non-kyanitic conglomerate lies stratigraphically beneath the thick belt of fine grained chloritoid schist, and consequently below these kyanite quartzites. A small outcrop of conglomerate at the upper contact of the schistose pyroclastic rocks east of Oak View Baptist Church may be the same bed as that under discussion.

The thickness of the conglomerate bed along the west limb of the syncline varies from about 45 feet to 100 feet. There are two offsets in the otherwise continuous trend of this bed. These offsets may represent sharp isoclinal folds.

The conglomerate consists of quartz grit grains (3 to 5 millimeters) and coarse pebbles of fine grained white quartzite, and locally pebbles of reddish quartzite and chloritoid schist. The pebbles vary from one fourth to 8 inches in length. The average size is 1 to 3 inches. The pebbles are usually flattened in the plane of foliation which is parallel to the bedding. The ratio of maximum to minimum length varies from 1:1 to 6:1; a common ratio is about 2 to 3:1.

The matrix of the conglomerate consists of very fine grained quartz (0.03 to 0.09 millimeter), mica, and chlorite with accessory amounts of magnetite, tourmaline, rutile, zircon, and, locally, garnet. In places, as at Lake Montonio, the matrix is entirely quartz.

Albite-Chlorite Schist

Fine grained schist or phyllite of this composition is found locally in the vicinity of Stepps Gap. It lies close to, and stratigraphically below, the kyanite conglomerate. Probably much of the phyllitic-looking rock in the two belts of chloritoid schist is similar to this schist.

The schist is fine grained and has a bluish gray color. At one exposure the schist contains a few 8 inch beds of conglomerate. In thin section the rock is seen to consist of fine grained, randomly oriented angular quartz and plagioclase (now albite), mica, chlorite, and minor amounts of biotite and magnetite. The clastic nature of the quartz and feldspar grains and the presence of moderate amounts of mica and chlorite suggest that the rock was a heterogeneous clastic sediment, perhaps a graywacke. Much of the detrital feldspar in this and other fine grained metasediments in this part of the section may be of tuffaceous origin.

Kyanite Quartzite

Introduction

The principal kyanite quartzite deposits are at Henry Knob, the Shelton property, The Pinnacle and Kings Mountain, and Crowders Mountain in the Kings Mountain-Henry Knob area; and at Club Mountain in the Reese Mountain-Clubb Mountain area.

The distribution and possible correlation of kyanite quartzite beds in the Kings Mountain-Henry Knob area are given in Figure 2. The correlation from one limb of the anticline (I) to another is not rigorous for it is based largely on the geometry of the overall outcrop pattern and the association of manganiferous schist with high alumina quartzite on the flanks of the anticline (I), (see Structure).

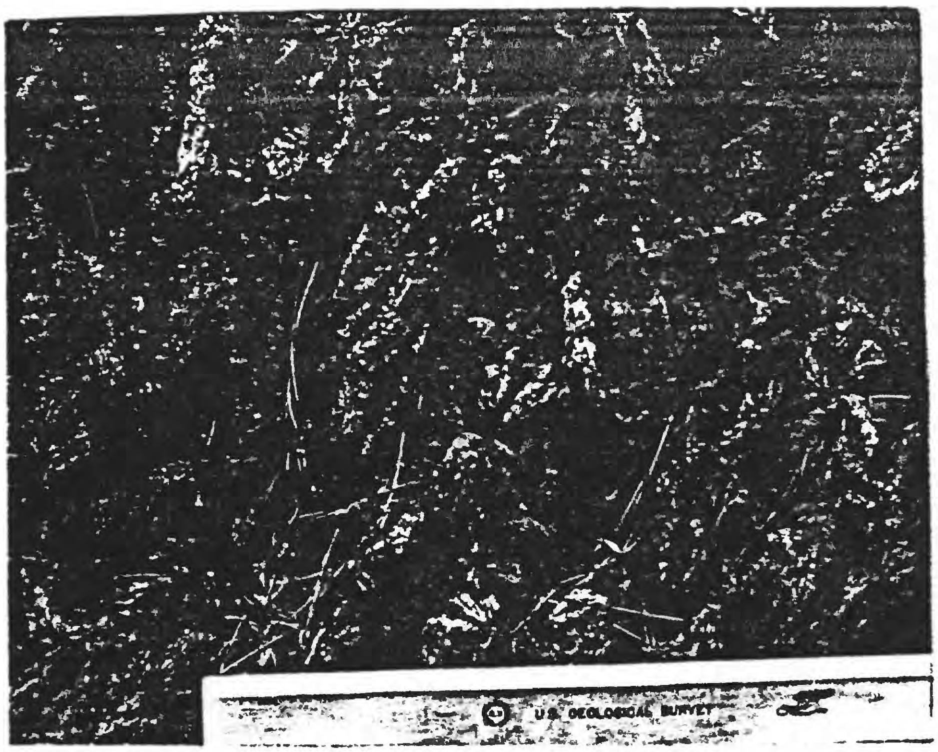
General Description

Size and Shape of Bodies

Kyanite quartzite generally occurs as well defined steeply dipping beds or lenses in sharp contact with surrounding schists or non-kyanitic quartzites. The width of individual kyanite quartzite beds varies from about 10 feet to 120 feet with 20 to 35 feet being a common average. Continuous beds of kyanite quartzite, gradational along strike with kyanite conglomerate and kyanite schist, are best exposed on the east limb of the syncline (II) in the northwest part of the area, (Plate I). One kyanite quartzite bed here is exposed continuously for three and one half miles. On both limbs in the southern half of this syncline, kyanite quartzite occurs as two parallel beds separated by 20 to 100 feet of mica schist or schistose conglomerate. Long single beds of kyanite quartzite occur along the east limb of the syncline (II) just south of Crowders Mountain Village; just south of McGill Creek, 1,000 feet west of the Yorkville granodiorite contact; and southwest of Henry Knob.

Figure 13. Foliated kyanite quartzite. Looking southeast along base of cliff at south end of The Pinnacle. Photograph by G.H. Espenshade.

Figure 14. Tufted aggregates of kyanite lying in plane of foliation in quartzite at the Shelton property. Scale is graduated in inches and tenths of inches. Photograph by W.C. Overstreet.


U.S. GEOLOGICAL SURVEY

Kyanite quartzite commonly occurs as long, thin, parallel or en echelon lenses. Some of these lenses may represent different lenticular sedimentary bodies, but in most cases the intensely folded nature of the rocks suggests that the lenticularity is a structural feature. Long parallel lenses of kyanite quartzite, in sharp contact with mica schist, are well exposed at the north end of Clubb Mountain (Plate VI) and Henry Knob (Plate III). In both cases the numerous long lenses probably represent one or two sedimentary bodies that have been repeated by folding.

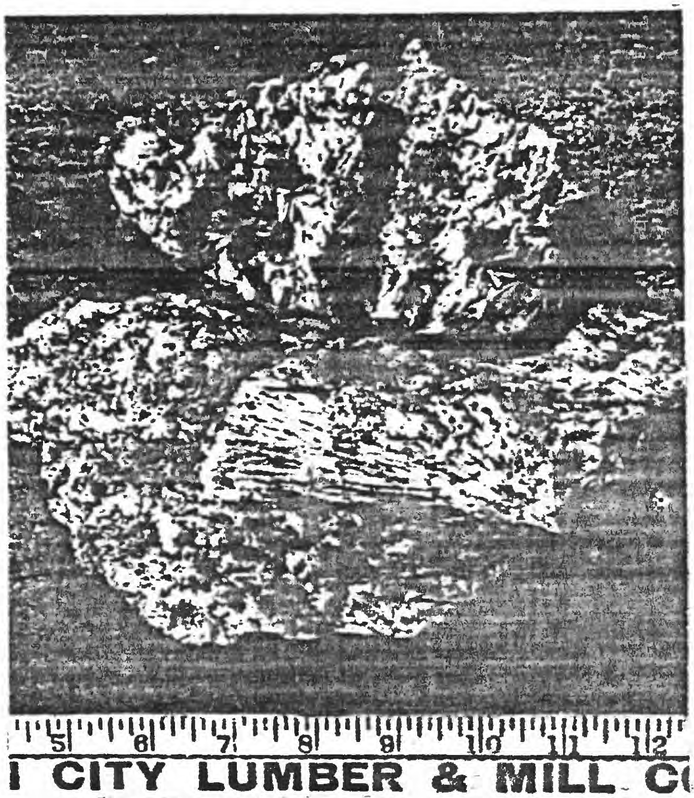
Much of the kyanite quartzite in the northern part of the Kings Mountain-Henry Knob area is interlayered with massive magnetiferous quartzite and staurolite quartzite. In some cases, as in the southern half of Crowders Mountain (Plate I), these rocks occur as continous interlayers for hundreds of feet along strike; but in several cases, as at the Shelton property (Plate IV), and along a low ridge southeast of Crowders Mountain, the regular interlayers are not well defined and kyanite quartzite, staurolite quartzite, and magnetiferous quartzite occur as irregular, highly lenticular masses.

Fabric

Kyanite generally occurs as colorless to light gray single blades, tufted aggregates, sprays and flattened radial aggregates evenly distributed along crude to well developed foliation planes in the quartzite (Figure 13). The tufted aggregates have a maximum length of about two to two and one half inches and are best developed in quartzite at Crowders Mountain and the Shelton property (Figure 14). Flat radial aggregates and sprays lying within the plane of foliation are well developed in the quartzite along Kings Mountain. Small cones or spherical aggregates of radiating blades occur locally at the Shelton property

Figure 15. Radiating aggregates of kyanite. Two samples at top from the Shelton property; sample at bottom is from thin layer underlying kyanite quartzite along Kings Mountain, 2200 feet northeast of Sherrars Gap. Scale is graduated in inches.

Figure 16. Coarse grained aggregates of blue kyanite in quartzite at north end of Clubb Mountain. Swirling trains in groundmass are iron stained mica. Scale is graduated in inches and tenths of inches. Photograph by W.C. Overstreet.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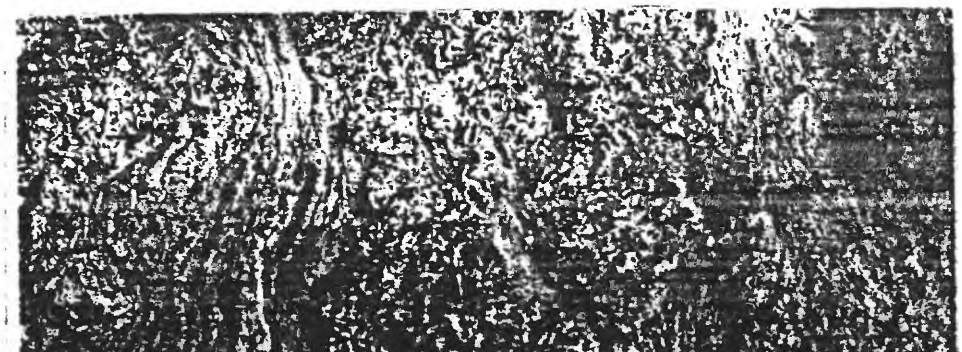


(Figure 15). Individual kyanite blades range from about 3 to 10 millimeters long. They are particularly well developed at the north end of The Pinnacle. Kyanite quartzite at Henry Knob has a crude foliation produced by subparallel and anastomosing aggregates of single kyanite blades. This foliation is most apparent on weathered surfaces; the fresh ore appears massive.

The tufted aggregates and individual blades generally define a strong lineation. This lineation lies invariably in the plane of foliation and is parallel to the small fold axes discussed beyond. The fabric of some of the kyanite quartzite at Clubb Mountain is distinctly different from other kyanite quartzite in the district. At Clubb Mountain kyanite occurs as clots or irregular aggregates of random coarse grained (average 10 millimeters), blue plates and blades (Figure 16). The aggregates vary from one inch to two feet in diameter and are generally set at random in the fine grained groundmass of quartz and mica.

Rare coarse grained aggregates of kyanite with little or no quartz occur in the otherwise homogeneous ore at Henry Knob. These aggregates range from about six inches to one foot in diameter and commonly occur at the axes of small folds. Individual kyanite blades in these aggregates are commonly one inch long; pyrophyllite forms thin coatings on some of the crystals. The fact that many of these aggregates occur at the axes of small folds suggests that there was some movement of alumina during deformation.

The quartz groundmass of kyanite quartzite is generally very fine grained. In several places, as at Clubb Mountain, the south end of The Pinnacle, and the south end of the zone of thin beds at Henry Knob, the groundmass contains several per cent mica. This mica is commonly iron stained from the weathering of pyrite in the rock. Mica and kyanite together define a strong foliation.

The conglomeratic nature of the kyanite quartzite is restricted to beds in the southern half of the syncline (II) in the northwest part of the Kings Mountain-Henry Knob area. The pebbles in the conglomerate consist almost entirely of fine grained white quartzite. The pebbles range from about one inch to three and one half inches in length and are commonly flattened in the plane of foliation. Thin kyanite aggregates occur in the interstices between the pebbles and along the well developed foliation planes in the rock. Kyanite conglomerate is gradational along strike to non-kyanitic schistose conglomerate, and also to kyanite quartzite.

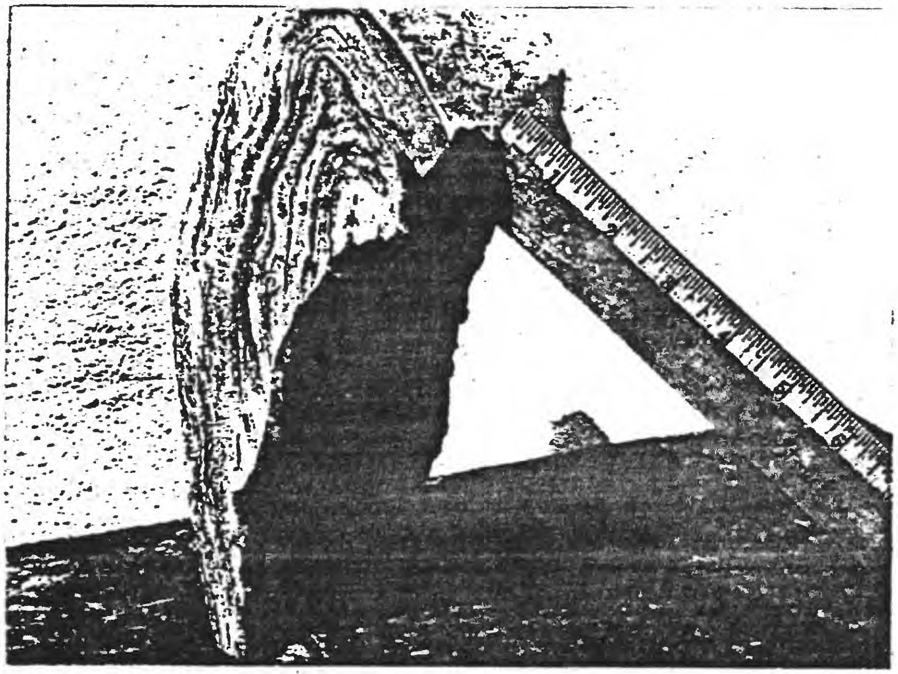
Compositional Layering

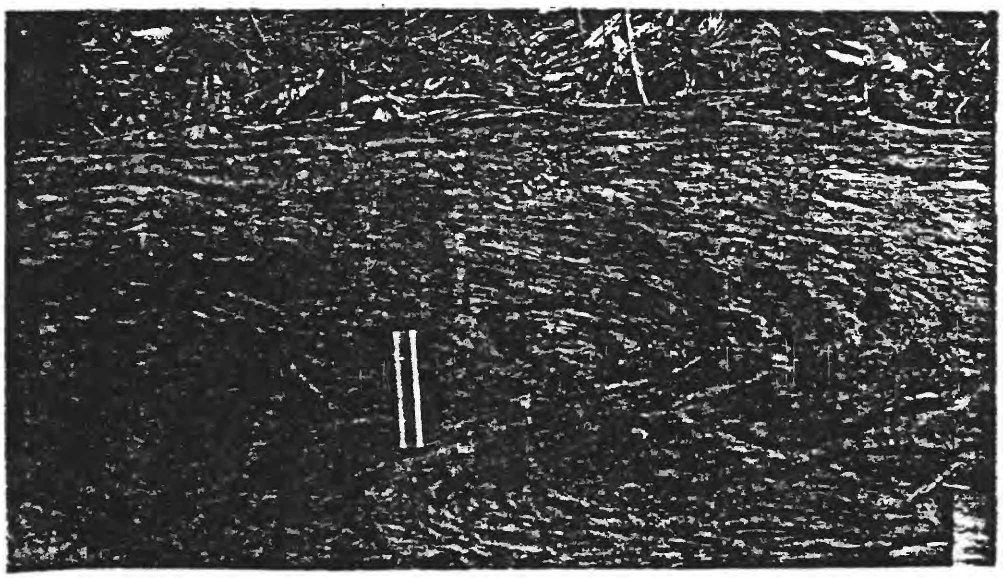
Thin kyanite-rich layers occur stratigraphically below the kyanite quartzite on Kings Mountain. These layers are from two to five feet thick and can be traced as far as 100 feet along strike. Their kyanite content varies from about 30 to 90 per cent. Kyanite commonly occurs as very coarse grained aggregates of radiating crystals up to 4 inches in diameter (Figure 15). These layers have sharp contacts with kyanite quartzite and schist.

Some of the coarse grained aggregates of blue platy kyanite at Clubb Mountain occur as discontinuous thin (1 to 3 inches) highly contorted layers in the quartzite groundmass. As many as 4 or 5 thin parallel layers occur in one small area. These layers, and the longer layers at Kings Mountain are believed to have been clay-rich layers in the sedimentary sequences.

Figure 17. Isoclinal fold in kyanite quartzite. Sample from crest of Crowders Mountain, east of radio tower. Note bands of non-kyanite quartzite (1), kyanite-mica quartzite (2), and kyanite quartzite (3). Scale is graduated in inches.

Figure 18. Isoclinal fold in kyanite quartzite at Crowders Mountain Looking down on vertically plunging fold. Scale is six inches long.





Along the east limb of the syncline (II, Figure 2) 1.2 miles south of Crowders Mountain Village, kyanite quartzite is interlayered with kyanite-chloritoid-staurolite quartzite (the petrology of this rock is discussed under a separate heading following the discussion of kyanite quartzite). The kyanite-chloritoid-staurolite quartzite occurs as a thin bed between two parallel beds of kyanite quartzite. Each of the three beds is about 10 feet thick and the contact between them is sharp. They can be traced for about 100 feet along strike.

Kyanite quartzite is interlayered, and in sharp contact with non-kyanitic quartzite and staurolite quartzite at Crowders Mountain. At the south end of Crowders Mountain, interlayers of kyanite quartzite and non-kyanitic quartzite can be traced for hundreds of feet along strike. Layers of staurolite quartzite are generally 10 to 20 feet thick and extend for distances up to 500 feet along strike. (The petrology of this rock is described later.)

Compositional layering on a smaller scale is seen in a small isoclinal fold at Crowders Mountain (Figure 17). The layering, which is parallel to the well developed foliation, consists of alternate bands of kyanite quartzite, non-kyanitic quartzite, and kyanite-mica quartzite.

Compositional layering was also seen in some thin sections and is described later.

Compositional Variation Along Strike

The gradation from conglomeratic to non-conglomeratic kyanite quartzite is generally gradual and takes place over a distance of several hundred feet. Likewise, gradations occur between mica-bearing and mica-free kyanite quartzite. At Clubb Mountain, mica-bearing kyanite quartzite grades along strike to kyanite schist.

Sharp variation in kyanite content along strike of the quartzite beds is not very common. The most notable abrupt change is in the conglomeratic beds on Kings Mountain northeast of Stepps Gap. Here, non-kyanitic conglomeratic quartzite is gradational over a distance of 200 feet to kyanite conglomerate carrying 10 to 15 per cent kyanite.

Compositional variations occur in beds along the east limb of the syncline (II) south of Crowders Mountain Village. Here, kyanitic schistose pyroclastic rock lies on strike with the kyanite-staurolite quartzite outcrop, suggesting that these two kyanite-bearing rocks are gradational.

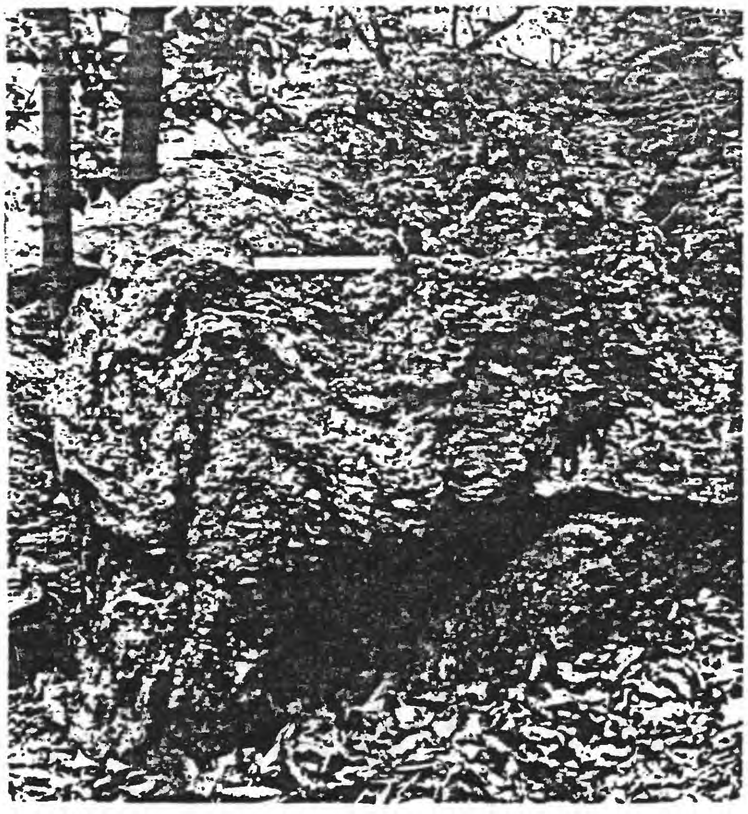
Kyanitic schistose pyroclastic rock occurs interlayered with kyanite conglomerate, and locally grades along strike to kyanite conglomerate at the northeast end of Kings Mountain.

Folding

At most localities in the Kings Mountain-Henry Knob area kyanite quartzite is characterized by profuse small folds. The amplitude and wave length of these folds is variable from about 6 inches to 20 feet. In general the folds are isoclinal and have very steep axial planes that parallel the foliation, (Figure 18). The axes of these small folds have a constant direction of plunge at some localities, as at Henry Knob, the Shelton property and the south half of Crowders Mountain. However, in the central and north part of Crowders Mountain, and The Pinnacle, the axes of small folds are vertical or horizontal, or plunge with variable magnitudes to the northeast and southwest. In some cases the axis of a small fold has itself been folded so that the fold has the shape of a cork screw, (Figure 19). The tortuous nature of much of the folding

Figure 19. Corkscrew fold in kyanite quartzite at Crowders Mountain, 400 feet south of radio tower. Scale is six inches long.

Figure 20. Tortuous folding of foliated kyanite quartzite at the Shelton property. Looking southwest along trend of outcrop. Scale is one foot long. Photograph by W.C. Overstreet.



is shown in Figure 20.

In general, even the consistently oriented small fold axes give few clues to the major structure (see Structure). The variable magnitude and random direction of plunge in areas such as the north end of The Pinnacle (Plate V), and near the radio tower at Crowders Mountain, suggest that these folds may have been produced by flowage of a whole bed of kyanite quartzite. Such flowage may, in large part, account for the thickening of quartzite beds at The Pinnacle (see cross sections in Plate V), and in the central part of Crowders Mountain where the total thickness of kyanite and non-kyanitic quartzite is from 700 to 1000 feet. An example of probably similar flowage is shown in quartz-mica schist in which thin quartzose layers are greatly thickened at the noses of very small folds (Figure 21).

Quartz Veins and Quartz-Kyanite Veins

Quartz veins, some of which carry small amounts of kyanite, cut the kyanite quartzite at The Pinnacle, Crowders Mountain and Clubb Mountain. In addition, small irregular masses of milky quartz are scattered through the quartzite and are quite numerous in the vicinity of local shear planes and small fold axes.

Quartz veins are generally a few inches to one and one half feet thick. Most are a few tens of feet long; one vein at Crowders Mountain is over 100 feet long. The quartz is very coarse grained and either colorless or milky. Many veins cut across the prominent foliation but others are parallel to it. At Crowders Mountain, the kyanite quartzite immediately adjacent to some of these veins is enriched in kyanite. A few of the veins at Crowders Mountain, and some at

The Pinnacle, carry small amounts of kyanite in the form of coarse radial aggregates. Contrary to what Smith and Newcombe (1951, p. 762) report, no kyanite veins were found at Henry Knob. (

Cross-cutting, coarse grained, quartz veins are abundant in the kyanite quartzite at the north end of Clubb Mountain. Not infrequently the veins carry one or more of the following minerals: lazulite, ilmenite and the calcium aluminum phosphate, crandallite. Lazulite occurs as random course grained anhedra and euhedra in quartz and, locally, as a thin median seam in one large quartz vein. Crandallite occurs as small, light gray pisolitic aggregates in one quartz mass. It was identified by R. L. Smith of the U.S. Geological Survey. Spectrochemical analysis indicates the major constituents to be:

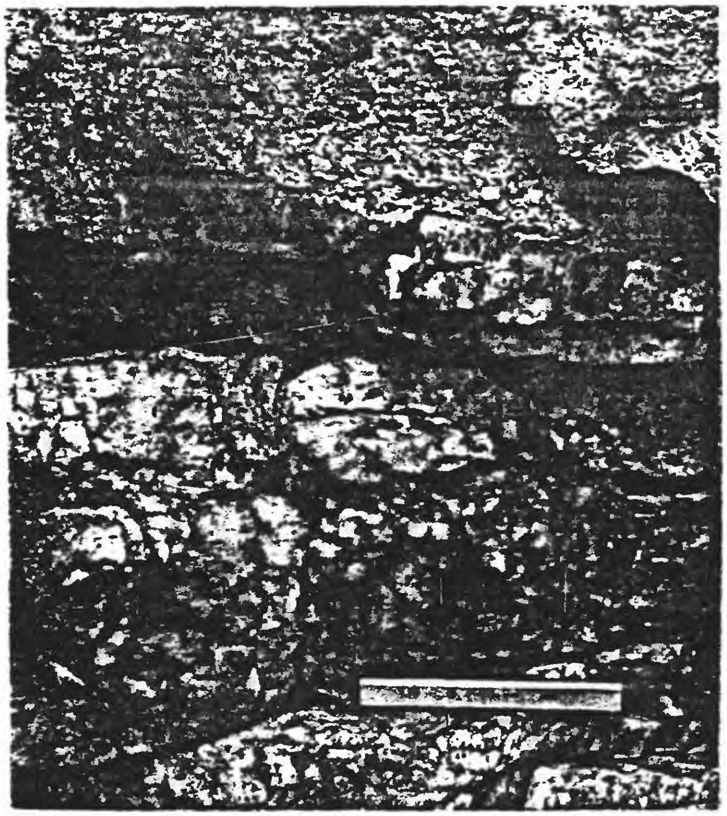
XO. : Al, Ca, P.

X. : Sr, Ba,

A large quartz vein with a selvage of kyanite occurs along the northwestern-most kyanite quartzite bed at the north end of Clubb Mountain. This vein is about 15 feet long and 3 to 5 feet thick. It consists of coarse grained milky quartz. A comb structure of vertically oriented elongate kyanite blades occurs at the top of this vein in sharp contact with the kyanite quartzite above (Figure 22). This comb consists of about 75 to 90 per cent kyanite with interstitial quartz. The kyanite in this comb fingers out gradually downward into the quartz. In addition to this comb of kyanite along the top of the vein, there exists at least one discontinuous layer of vertically oriented comb kyanite in the middle of the vein. Comb kyanite occurs discontinuously along the top and sides of the vein about 10 feet

Figure 21. Small folds developed in fine grained quartz-mica schist. Looking down on outcrop just east of dam at Crowders Mountain Village. Note that thin quartz layers are greatly thinned on limbs of folds and thickened at noses. Scale is graduated in inches and tenths of inches. Photograph by W.C. Overstreet.

Figure 22. Quartz-kyanite vein in kyanite quartzite about 400 feet northwest of where access road crosses crest of ridge at north end of Clubb Mountain. Note sharp contact between vertically oriented comb of kyanite at top of vein and kyanite quartzite; the vein is practically horizontal; foliation in kyanite quartzite is parallel to plane of photograph. Bulk of vein in this view is milky quartz. Scale is one foot long. Photograph by W.C. Overstreet.



north of the point where the picture was taken. Here the vein is parallel to the foliation. Comb kyanite also occurs locally along a curved fracture in the vein quartz and its location here suggests that the kyanite occurs where movement along the fracture had opened up spaces.

The foliation in the kyanite quartzite is locally warped from its vertical orientation to near parallelism with the upper contact of the quartz vein yet the vein has not been deformed. The vein is clearly younger than the development of foliation. A thin section of this quartzite shows it to consist of typically fine grained quartz, and coarser grained, poorly defined blades of kyanite. Some of the kyanite is fractured and embayed by quartz, and perhaps partially replaced by quartz. (see thin section petrology).

The kyanite-quartz vein is clearly younger than the development of foliation in the kyanite quartzite, and hence probably younger than the development of kyanite along foliation planes in the quartzite. The bending of foliation at the contact of the vein, and the ragged and fractured nature of some of the kyanite as seen in thin section suggest strong local deformation in this vicinity; the vein was probably emplaced along a shear zone. The evidence suggests that kyanite and quartz material moved into the vein at about the same time; the presence of comb kyanite in a fracture in the quartz indicates that the kyanite finished crystallizing later than the quartz.

Two facts suggest that the quartz and kyanite in the veins at Clubb Mountain and in the Kings Mountain-Henry Knob area were derived by metamorphic differentiation of the kyanite quartzite:

(1) Quartz veins are more numerous in quartzite than in adjacent schist.

(2) Kyanite-bearing quartz veins are restricted to kyanite quartzite and are not found in the adjacent schists.

Differentiation probably involved a secretion of the more soluble materials from the quartzite into fractures. This probably took place in response to local shearing; hydrothermal fluids may have played an important part in mobilizing the quartz and kyanite. The fact that there has been at least some local mobilization (either mechanical smearing or solution) of kyanite is convincingly shown in the kyanite quartzite at Clubb Mountain by the presence of a thin coating of fine grained kyanite along slickensided fault surfaces. The presence of minor amounts of crandallite and lazulite in some quartz veins indicates at least a minor role for hydrothermal fluids. The fact that quartz, alone, forms the bulk of the veins suggests that this mineral was more soluble than kyanite. A similar theory is suggested by Chapman (1950) to account for quartz veins with staurolite-rich borders; likewise, Read (1934) suggests that the kyanite-bearing quartz veins, in kyanite schists of the Shetland Islands, were produced by endogenous secretion.

Thin Section Petrology

The features discussed below are common to the kyanite quartzite in the Kings Mountain-Henry Knob area and to much of the kyanite quartzite at the north end of Clubb Mountain. Certain special features of the kyanite quartzite at Clubb Mountain, are discussed under a separate heading.

TABLE V

Chemical and modal analyses of the kyanite quartzite from Henry Knob, York County, South Carolina.

1.		2.		3.		4.	
SiO_2	73.56	Quarts	63.3	Quartz	65.5	Quartz	73.2
Al_2O_3	17.01	Kyanite	27.00	Kyanite	27.6	Kyanite	22.3
Fe_2O_3	.00	Pyrite	8.66	Pyrite	6.9	Pyrite	4.0
FeO	5.25*	Rutile	.48	Rutile	.27	Rutile	.2
MgO	.01	Lazulite	.23		100.27	Muscovite	0-.7
CaO	.00		99.67			Barite?	0-.3
Na_2O	.00						99.7
K_2O	.00						
H_2O-	.01						
H_2O-	.12						
TiO_2	.48						
CO_2	.01						
P_2O_5	.11						
S	4.62						
MnO	.00						
Less O	101.18						
for S	1.16						
	100.02						

1. Chemical analysis of kyanite quartzite. Sample is a composite of six specimens taken throughout the length of the northern quarry. Analyst: Lucille N. Tarrant, U.S. Geological Survey.

2. Weight per cent of minerals calculated from chemical analysis in Column 1.

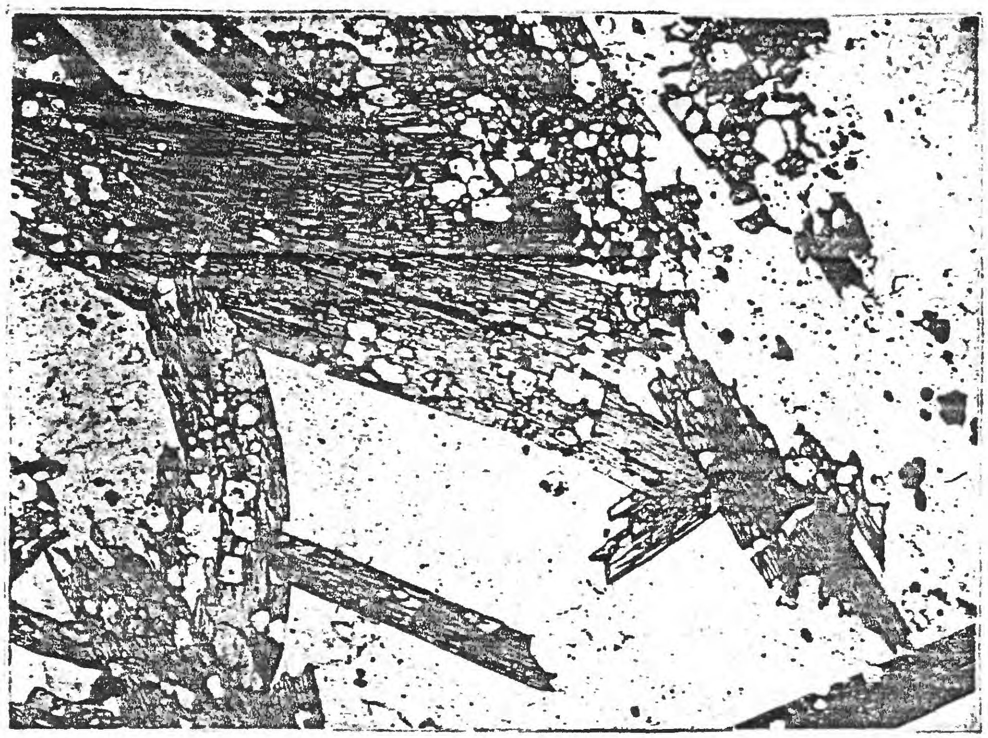
3. Weight per cent of minerals calculated from the mode given in Column 4.

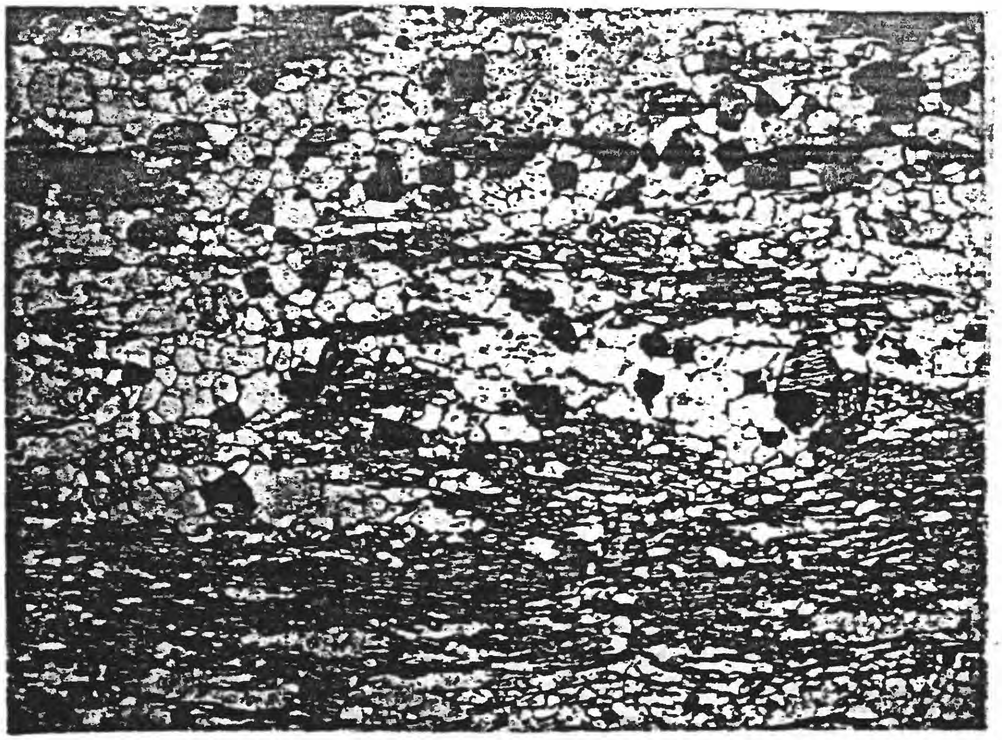
4. Modal analysis of kyanite quartzite; an average of nine thin sections (500 points counted in each) of specimens taken at random from open pits at crest of hill.

* The FeO content was calculated from the sulphur content assuming that all sulphur is present as pyrite (FeS_2).

Figure 23. Photomicrograph of kyanite quartzite. Sample from creek bed, south of transmission line at north end of Clubb Mountain. Minerals are: poeciloblastic kyanite (high relief), quartz (white), and pyrite (opaque). Note thin train of inclusions in quartz embayment in lower part of bent crystal. This train may mark margin of that portion of crystal replaced by quartz. Note quartz filling cross fracture in kyanite blade on right side of picture. Plain light, X 25.

Figure 24. Photomicrograph of kyanite quartzite. Sample from crest of Crowders Mountain east of radio tower. Typical anhedral habit of much kyanite (high relief) in the district. Opaque mineral is pyrite; white mineral is quartz. Plain light, X 25.





Quartz and kyanite generally constitute from about 92 to 98 per cent of the rock. Lesser constituents are mica (trace to 5 per cent) and pyrite (trace to 8 per cent). Rutile, magnetite and zircon are common accessory minerals. Rare accessory minerals include apatite, barite, lazulite, tourmaline, and pyrophyllite.

The kyanite content usually ranges from about 5 to 35 per cent. Chemical, and modal analyses of kyanite quartzite ore at Henry Knob are given in Table V . In addition to the Henry Knob deposit, kyanite is most abundant in quartzite at the Shelton property, the north end of The Pinnacle, the north end of Crowders Mountain, and the north end of Clubb Mountain. The typical occurrence of kyanite is as subhedral to anhedral elongate porphyroblasts, ranging from a fraction of 1 millimeter to 6 millimeters in length, evenly distributed through the very fine grained quartz groundmass.

The habit and appearance of kyanite is variable from well formed blades holding few or no inclusions of quartz to highly poecilo-blastic blades with rounded inclusions and irregular embayments of quartz (Figure 23). The most common form of kyanite is as irregular anhedra and aggregates of anhedra (Figure 24). In some cases, the poeciloblastic texture has undoubtedly resulted from the incorporation of small quartz grains in the porphyroblasts. This texture may also have resulted from the liberation of SiO_2 as small areas of pure clay (kaolinite) recrystallized to kyanite. This recrystallization may be thought of in terms of the following equation:

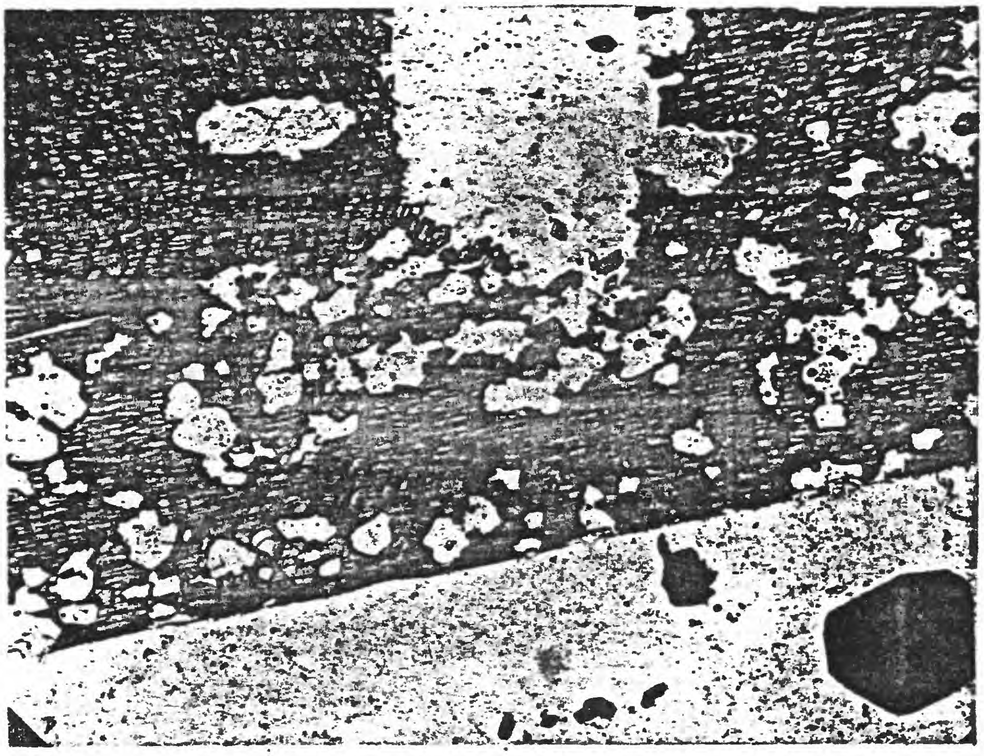
$$\underset{\text{kaolinite}}{Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O} \rightarrow \underset{\text{kyanite}}{Al_2O_3 \cdot SiO_2} + \underset{\text{quartz}}{SiO_2} + 2H_2O$$

Smith and Newcombe (1951) interpret the highly poeciloblastic nature of the margins of kyanite blades at Henry Knob to indicate replacement of quartz by kyanite. In the present study, several thin sections of kyanite quartzite from Henry Knob and one from Club Mountain show kyanite with highly poeciloblastic margins. The quartz embayments and inclusions are generally about 0.1 millimeter in diameter—the size of the smallest grains in the groundmass and probably one fifth to one third the size of some of the quartz grains in the parent sediment (see beyond). The following evidence suggests that quartz may have partially replaced kyanite: the margin of the kyanite blade, though partially riddled with quartz, shows the straight prismatic face along portions not embayed by quartz and, furthermore, a narrow train of very fine grained inclusions occurs in the quartz embayment in line with the prismatic face (Figure 25; Figure 23) suggesting that the thin train of inclusions marks the margin of the replaced section of kyanite. The margins of some kyanite blades are so riddled with quartz that there are no remnants of a prismatic face.

Thin sections of kyanite quartzite from nearly every deposit in the district indicate cataclastic effects that Harker (1932, p. 356) attributes to retrogressive metamorphism. Some kyanite blades have been slightly bent, fractured, faulted or pulled apart. In most of these cases, and especially at Henry Knob, quartz has filled the fractures and irregular ruptures. Single crystals of quartz also occur as long fingers along cleavage planes in kyanite. Rarely, the ruptured areas in kyanite are filled with a micaceous aggregate; and the margins of some kyanite blades are rimmed by very fine grained aggregates of clay.

Figure 25. Photomicrograph of kyanite quartzite. Sample from Henry Knob. Minerals are: kyanite (poeciloblastic, high relief), quartz (white), pyrite(opaque). Large white area at top is hole in thin section. Note thin train of inclusions in quartz embayments into kyanite that are in line with lower margin of kyanite blade. Plain light, X 65.

Figure 26. Photomicrograph of kyanite-chloritoid quartzite. Sample from thin bed 1.2 miles S10W of Crowders Mountain Village. Minerals are: chloritoid (radial aggregates), kyanite (long fibrous aggregates), quartz (fine grained white and gray). Crossed nicols, X 25.



The groundmass of kyanite quartzite generally consists of a mosaic of very fine to fine grained quartz. Individual grains are generally 0.05 to 0.5 millimeter in diameter. In some cases the groundmass is inequigranular, the range being from 0.01 to two millimeters. Only the larger grains show well developed strain shadows. Very coarse grained (9 millimeters) quartz occurs interstitial to some of the coarse tufted aggregates of kyanite at the Shelton property. In some cases a distinct layering is defined in the groundmass by alternate bands of fine grained and medium grained quartz. Some of the coarse grained bands in kyanite quartzite at The Pinnacle may be highly flattened quartzite pebbles.

In one thin section of kyanite quartzite from Clubb Mountain, a distinct grain size variation of quartz and kyanite defines layers that are parallel to the foliation (and contact of adjacent schist). From one end of the thin section to the other the sequence is: one and one half centimeters—coarse grained random kyanite with very fine grained micaceous aggregates in a groundmass of inequigranular quartz; one centimeter—fine grained kyanite with well defined flakes of mica in a groundmass of fine grained quartz; one half centimeter—fine grained quartz-mica schist with fine grained topaz (?) (+ 2V 50 to 60 degrees, n less than 1.64), and minor kyanite.

Inclusions of very fine grained rutile, mica, and unidentified opaque minerals occur sparingly in the groundmass of most thin sections. One thin section of ore from Henry Knob shows a network of fine grained mica inclusions in the groundmass that suggests an interstitial coating about original grain boundaries. These original grains in the sandstone were about 0.3 to 0.5 millimeter in diameter, judging from the network of inclusions.

When present, mica occurs as fine grained inclusions in the groundmass and as well formed flakes intergrown with kyanite.

The pyrite content is highest in kyanite quartzite at The Pinnacle and at Henry Knob. It constitutes from about 7 to 8 per cent of the ore at Henry Knob (Table V). Pyrite content is variable within a single quartzite lens. In thin section it is seen to occur as fine to coarse grained pyritohedrons and subhedral and anhedral forms. Pyrite is commonly concentrated along foliation planes and at grain boundaries. At Henry Knob pyrite occurs as interstitial wedges between intersecting kyanite blades. Some small pyrite crystals occur along the tenuous fractures within strained quartz grains. This evidence from Henry Knob indicates that the growth of pyrite was a late phenomenon that took place after the recrystallization of quartz and deformation of kyanite.

Rutile is a very widespread accessory mineral. It is generally evenly distributed through the rock and occurs as very fine grained (0.02 to 0.3 millimeter) inclusions in quartz and kyanite. Magnetite is fairly widespread and generally occurs as fine anhedral to euhedral grains disseminated through the groundmass, although in some rocks from The Pinnacle and Crowders Mountain it is concentrated in distinct bands and inclusion trains.

Many thin sections contain a few fine grained zircon crystals. Some crystals appear distinctly fragmental while others are perfect doubly terminated crystals. Apatite occurs as fine grains in some of the kyanite quartzite at The Pinnacle and just southeast of The Pinnacle.

Apatite is typically anhedral; some grains are elongated and curved parallel to the wavy foliation planes. Barite occurs as a minor accessory mineral at Crowders Mountain, The Pinnacle, and Henry Knob. Barite is generally fine grained and interstitial to quartz grains in the groundmass. At Henry Knob and southeast of Crowders Mountain it occurs locally in thin veins that cut the kyanite quartzite. Bluish green lazulite occurs locally at Henry Knob as fine grains disseminated in kyanite quartzite. Lazulite is a common accessory mineral in the rock at Clubb Mountain. Tourmaline is a very rare accessory mineral in most kyanite quartzite. It occurs as small subhedral grains in the kyanite quartzite at The Pinnacle. Pyrophyllite was identified in some of the coarse grained kyanite aggregates at Henry Knob. Judging from the absence of Na_2O and K_2O in the kyanite quartzite at Henry Knob (Table V) it is probable that the few fine grained scattered flakes and inclusions of what appear to be mica are really pyrophyllite.

Special Features of Kyanite Quartzite at Clubb Mountain

The kyanite quartzite lenses at the north end of Clubb Mountain (Plates II and VI) contain sporadically distributed coarse grained aggregates of blue kyanite (Figure 16). These aggregates range from about one inch to two feet in length. Most have lenticular or rounded shapes but some are elongate in the plane of foliation and appear to be thin layers in the quartzite.

Coarse grained (one half to one centimeter) blue platy kyanite constitutes from about 40 to 90 per cent of each aggregate. Other constituents, usually interstitial to the kyanite, are quartz, pyrophyllite, and lazulite. Rutile is a widespread accessory and occurs as fine grained inclusions in kyanite and also as coarse grained (up to one and one half centimeters) random crystals and crystal aggregates.

Thin sections of these coarse aggregates show the kyanite to be clear, well formed blades or plates with few quartz inclusions. Kyanite is generally sheathed by, or is altering along cleavage planes, to a slight degree to, clay. Pyrophyllite occurs as well defined interstitial radial aggregates, and as incipient veins and stringers cutting the kyanite. Quartz occurs as small or large interstitial grains molded to the wedge-shaped interstices between the randomly oriented kyanite blades. Pearly white flakes of mica occur frequently with these coarse grained aggregates of kyanite but pyrophyllite is probably more abundant.

At the south end of Clubb Mountain, lying on strike with the kyanite quartzite to the north, is a lens-like body of coarse grained kyanite-pyrophyllite-lazulite rock. The kyanite quartzite immediately north of this lens is altered to clay, the contact between this altered rock and the kyanite-pyrophyllite-lazulite rock appears to be sharp.

The kyanite-pyrophyllite-lazulite rock consists of interlocking coarse grained (one centimeter) well formed, bluish platy kyanite, with interstitial pyrophyllite, quartz, and lazulite. The percentage of pyrophyllite is variable from about 5 to 90 per cent. (over what domain?) Aside from the abundance of pyrophyllite and lazulite, and the presence of some different accessory minerals, this rock is similar to the coarse grained kyanite aggregates in the quartzite at the north end of the mountain.

Pyrophyllite occurs as coarse grained radiating aggregates, and is seen in thin section to have replaced kyanite to a small degree.

Could not radial kyanite have replaced pyrophyllite?

Lazulite occurs as coarse grained euhedral crystals in the large interstices between kyanite blades, and as small inclusions in the kyanite. Clay occurs in this rock in the interstices between well formed and unreplaced kyanite.

Accessory minerals found in this rock are rutile, pyrite, tourmaline, andalusite (?), diaspore, hamlinite, and zunyite.

Pyrite occurs as coarse and fine euhedra scattered through the rock. Black tourmaline is a rather common accessory and is seen in thin section to be interstitial to the coarse kyanite. Andalusite (?) is a minor accessory interstitial to the kyanite. Diaspore generally occurs as small, poorly defined blades or aggregates which finger into, and cut across, the kyanite. A few well formed coarse blades of diaspore occur in two thin sections. Hamlinite occurs as small tabular crystals lining the wedge-shaped interstices between kyanite blades, and is commonly associated with clay. Zunyite occurs as coarse (5 millimeters) euhedral bipyramidal crystals imbedded in a rock consisting of about 75 per cent pyrophyllite. (Zunyite is clear, $H > 5$, isotropic, $n = 1.597$.) A few quartz crystals up to one and one half centimeters long were found on the dumps of prospects dug in the pyrophyllite-kyanite rock. Some of these crystals contain small flakes of hematite or graphite as oriented inclusions.

Quartzites Containing Staurolite, Chloritoid and Kyanite

As noted earlier, quartzites containing these minerals occur as interlayers with kyanite quartzite and non-kyanitic magnetiferous quartzite south of Crowders Mountain Village, at Crowders Mountain, at the Shelton property, and along a low ridge southeast of Crowders Mountain.

The quartzite is generally brownish or gray, fine grained, and very tough. Foliation is moderately well developed.

The following estimated modal range is based on several thin sections of the rock from each locality:

quartz	25 - 75 per cent
staurolite	Trace - 75 per cent
chloritoid	Trace - 97 per cent
kyanite	0 - 35 per cent
magnetite	Trace - 25 per cent

accessory mica, andalusite, rutile, pyrite, zircon, tourmaline, and biotite.

Staurolite is the principal high alumina mineral and kyanite is generally absent in this quartzite at the Shelton property and Crowders Mountain. At these localities staurolite occurs as fine grained euhedra or ragged anhedra set in a very fine grained groundmass of quartz. Magnetite generally makes up less than 5 per cent of the rock, but locally, at one prospect on Crowders Mountain, constitutes 25 per cent and occurs as coarse grained euhedra intergrown with staurolite. When present, andalusite occurs as fine to medium grained ragged anhedra into which staurolite crystals have penetrated.

Chemical and modal analyses are given of chloritoid-kyanite quartzite (Table VI) that occurs 1.2 miles south of Crowders Mountain Village. The relative abundance of staurolite, chloritoid or kyanite is variable along strike of this bed. This rock has a strong lineation produced by the alignment of coarse grained kyanite blades. The groundmass consists of fine grained gray quartz and small scattered porphyroblasts of dark gray chloritoid.

TABLE VI

Chemical and modal analyses of chloritoid-kyanite quartzite, from a narrow bed, 1.2 miles S10W of Crowders Mountain Village, Gaston County, North Carolina.

1.		2.	
SiO_2	63.35	Quartz	48.5
Al_2O_3	28.97	Kyanite	34.4
Fe_2O_3	2.25	Chloritoid	14.9
FeO	2.50	Magnetite	1.7
MgO	.31	Staurolite	0.3
CaO	.07		99.8
Na_2O	.13		
K_2O	.04	Accessory andalusite, zircon and rutile.	
H_2O-	.05		
H_2O+	1.30		
TiO_2	.86		
CO_2	.01		
P_2O_5	.09		
S	—		
MnO	.05		
	99.98		

1. Chemical analysis of chloritoid-kyanite quartzite. Sample is a composite of six specimens taken across strike in a ten foot bed. Analyst: Lucille N. Tarrant, U.S. Geological Survey.

2. Modal analysis of one of the specimens of this rock used in making the sample for chemical analysis; an average of two thin sections, 1000 points counted in each.

Two thin sections of this quartzite show a distinct compositional banding produced by thin layers rich in kyanite-chloritoid-magnetite, staurolite, quartz-staurolite-chloritoid, and magnetite-quartz. Kyanite, staurolite and chloritoid occur as well formed porphyroblasts (Figure 26). Kyanite and staurolite are intimately intergrown; several kyanite blades have outer margins and cappings of staurolite. Andalusite occurs as medium grained anhedra penetrated and partially segregated by blades of kyanite, staurolite, and chloritoid. Some andalusite has been reduced to fine grained remnants resembling linked sausage. Clearly, andalusite has been partly replaced by kyanite, staurolite, chloritoid and perhaps by mica and quartz. Chloritoid and staurolite are intimately intergrown. It is not clear if one mineral has replaced the other or if the two have developed at the same time, but the following features suggest that staurolite has partly replaced chloritoid: euhedral crystals of staurolite project into and partly segregate radiating clusters of chloritoid; some of the chloritoid in contact with euhedral staurolite is poorly formed and clouded with small vermicular inclusions of quartz. The relation between chloritoid and staurolite is thought to be critical in determining metamorphic facies (see Metamorphism).

Magnetiferous Quartzite

Massive to crudely foliated, medium gray, fine grained quartzite is abundant in the central and southern parts of Crowders Mountain. It is interlayered with kyanite quartzite. Magnetiferous quartzite also occurs with kyanite quartzite in highly folded lenses southeast of Crowders Mountain and at the Shelton property.

This quartzite generally consists of about 90 to 98 per cent fine grained quartz, 2 to 10 per cent magnetite, and minor amounts of mica, staurolite, and, rarely, kyanite. In many cases the rock shows a suggestion of bedding by the presence of magnetite-rich and magnetite-poor bands.

In thin section the quartzite is seen to be a mosaic of fine grains (0.1 to 0.3 millimeter) of quartz. Magnetite occurs as anhedral to euhedral crystals ranging in size from 0.2 to 1.5 millimeter.

A lens of hematite schist about 5 feet wide and 20 feet long is in sharp contact with magnetiferous quartzite south of the access road at the crest of Crowders Mountain. This schist has a strong foliation and consists of about 70 per cent specular hematite, and 30 per cent quartz. The hematite has a reddish brown streak and is slightly magnetic. It may be maghemite or a very fine grained mixture of magnetite and hematite. Just north of the lens, thin veins of magnetite cut the magnetiferous quartzite. Thin veins of magnetite also cut kyanite conglomerate at Kings Mountain. These veins may have formed as some of the iron in the iron-rich beds and lenses was mobilized in the late stages of metamorphism.

Clay Alteration

Extensive hydrothermal alteration of kyanite quartzite to clay occurs at Crowders Mountain and Clubb Mountain. Complete pseudomorphs of clay after radial aggregates of kyanite [or pyrophyllite] occur locally at the north end of the Shelton property.

The clay at Crowders Mountain has been identified as dickite by R.L. Smith of the U. S. Geological Survey. Judging from the similar nature of occurrence, mineral associations, and appearance in thin section, the clay at Clubb Mountain is also probably dickite.

At Crowders Mountain (Plate I) the kyanite quartzite over an area of about 160,000 square feet has been veined and partly replaced by clay. The quartzite in this area has been faulted and sheared. Many slickensided fault surfaces are coated with clay. In general, the clay alteration appears to finger out to the north in two long projections parallel to the foliation.

The clay alteration in the central part of Clubb Mountain (Plate II) occurs over a distance of 3,000 feet. The kyanite quartzite here occurs as a single bed with a maximum thickness of 100 feet; a few narrow lenses of kyanite quartzite occur nearby and they are also altered to clay.

In both areas the nature of the replacement in the field and the thin section petrology of the altered rock are much the same. All gradations occur between incipient microscopic veins of clay in the quartzite to veins about one quarter to one half inch wide. Complete pseudomorphs of clay after kyanite were seen in thin section; in both areas, much of the quartz groundmass, as well as kyanite has been replaced by clay. Andalusite is present as partially replaced porphyroblasts in the rock from both areas. Unaltered sillimanite occurs locally in the altered rock at Clubb Mountain. The significance of andalusite and sillimanite in this rock is discussed under Metamorphism. Accessory minerals, probably in the quartzite before replacement, include rutile and mica.

In both areas the clay is commonly accompanied by small amounts of the strontium phosphate, hamlinite. Hamlinite has the following properties: rectangular tabular crystals and anhedra, uniaxial positive and biaxial positive, 2V = 5 to 10 degrees, n_o = 1.635, n_e = 1.644.

Clay alteration is believed to be the late hydrothermal stage in the development of the metamorphic minerals at Clubb Mountain, (see Origin of High Alumina Rocks). The alteration at Crowders Mountain is undoubtedly of the same age.

Associated Schists (See also Schistose Pyroclastic Rock, Chloritoid Schist, and Quartz-Mica Schist.)

Throughout the district, kyanite quartzite occurs in sharp contact with strongly foliated fine grained quartz-mica schists. In a few cases kyanite quartzite grades along strike to kyanitic schist.

Some of the schist in contact with kyanite quartzite at Crowders Mountain, Kings Mountain, and south of Crowders Mountain Village has the distinctive relict texture of the schistose pyroclastic rock. At all other deposits the schist was derived from fine grained clastic sediments, and perhaps also from pyroclastic rock whose distinctive texture has been destroyed by metamorphism.

The high alumina nature of the schists adjacent to kyanite quartzite is indicated by the presence of abundant mica and small amounts of one or more of the following minerals: chloritoid, andalusite, kyanite, and staurolite.

The following tabulation indicates the distribution of these minerals in schists at the various deposits.

Mineral	Present in schist at
andalusite	Henry Knob Crowders Mountain Shelton property Kings Mountain
kyanite	Kings Mountain Crowders Mountain Henry Knob Clubb Mountain (2 to 5 per cent)

Mineral	Present in schist at
staurolite	Henry Knob Crowders Mountain
chloritoid	Kings Mountain The Pinnacle

The only exception to the occurrence of quartz-mica schist immediately adjacent to kyanite quartzite is the very local occurrence of chlorite-albite schist on Kings Mountain, northeast of Stepps Gap. This schist is a metamorphosed fine grained clastic sediment. The fact that this rock belongs to the greenschist facies casts some interest on the origin and nature of development of the nearby kyanite (see Metamorphism).

Sillimanite Quartzite

Distribution

Well defined thin beds and lenses of sillimanite quartzite occur close to the Yorkville granodiorite contact in both the Kings Mountain-Henry Knob and Reese Mountain-Clubb Mountain areas, (Plates I and II). In both areas the sillimanite quartzite beds are generally within 2,000' feet of the granodiorite contact; sillimanite quartzite at Reese Mountain lies about 4,000 feet from the contact. Numerous long narrow septa of sillimanite schist and sillimanite quartzite occur in the granodiorite in the Kings Mountain-Henry Knob area.

The principal occurrences in the Kings Mountain-Henry Knob area are:

(1) The Will Knox property, and

(2) The Ryan-Purcley property (Figure 2, Plate I).

The principal occurrences in the Reese Mountain-Clubb Mountain area are:

(1) Reese Mountain, Lincoln County, and

(2) Just west and southwest of Machpelah Church, three miles northeast of Reese Mountain, (Plate II).

General Description

Sillimanite quartzite occurs as tough, resistant lenses and beds. These bodies form narrow craggy ribs that rise a few feet above the surrounding schists and gneisses. Sillimanite is generally evenly distributed through the quartzite as thin bone-white matts or flattened pencil-like aggregates varying from a few millimeters to about three and one half centimeters in length. These matts generally define a strong foliation in the quartzite but in many areas the quartzite has a massive fabric produced by randomly distributed and anastomosing stringers and matts of sillimanite. The matts consist of extremely fine fibers (fibrolite) of sillimanite.

Sillimanite quartzite commonly occurs as one, two, or more thin parallel beds cropping out over a width of less than 200 feet, and interlayered with quartz-mica schist or non-sillimanitic quartzite as at the Ryan-Purcley property and Machpelah Church; or as a pair of parallel beds, separated by as much as 800 feet of schist as seen north and south of the Will Knox property and at Reese Mountain.

Individual beds vary from three feet to about forty feet in thickness; 10 to 30 feet is a common thickness. Many beds are highly lenticular as at the Will Knox property where folding is conspicuous (Plate VII). Others can be traced along strike for distances up to 2,000 feet, as south of the Ryan-Purcley property and Machpelah Church, or 3,000 feet, as north of the Will Knox property.

Thin lenses of sillimanitic quartz-mica schist occur within the beds of sillimanite quartzite at some of the deposits. At several localities the sillimanite quartzite is gradational along strike to sillimanite schist. This is well shown in the two parallel beds 0.8 miles southeast of the Will Knox property.

Small pods and lenses of medium grained (1 to 3 millimeters) granular quartzite with little or no sillimanite are common within the sillimanite quartzite at the two occurrences in the Kings Mountain-Henry Knob area. These lenses are generally a few feet in length. Occasionally this barren quartzite carries minor amounts of fibrolite and pyrite.

Large lenses and irregular masses of coarse grained granular massive quartzite, with little or no sillimanite, also occur at the Ryan-Purcley property and at the Will Knox property. Some of these bodies are as much as 600 feet long and 100 feet wide. This quartzite is seen in thin section to be highly inequigranular. In addition to traces of sillimanite it carries accessory magnetite, pyrite, lazulite and muscovite, and very fine grained inclusions of zircon and rutile. The coarse grained granular quartzite at the Ryan-Purcley property carries minor amounts of fine grained native sulphur. Small pieces of float of andalusite schist occur in the area of outcrop of coarse granular quartzite at the Will Knox property. In several cases at the Will Knox property there seems to be a gradation along strike from sillimanite quartzite to coarse grained granular quartzite, although they are sharply separated across strike. This is also seen at the outcrops 1,200 feet north of the crest of Reese Mountain. The outcrop pattern of the large lenses and irregular masses of coarse grained granular quartzite suggest that they are, in part, original interlayers with the sillimanite quartzite. Thus, at the Machpelah Church area and the northwest slope of the Ryan-Purcley property, coarse granular quartzite occurs in bodies a few feet to about 15 feet wide and up to about 1,000 feet long. These bodies are interlayered with sillimanite quartzite and sillimanite schist.

In conclusion it is believed that the interlayered nature, and the gradation along strike of some of these coarse grained non-sillimanitic quartzite to sillimanite quartzite points to an original sedimentary origin for both.

The outcrop pattern and linear structures, defined by small plunging folds and elongate pencil-like aggregates of fibrolite in several areas, indicate the intensity of folding. This is particularly true at the Ryan-Purcley property and in the vicinity of, and to the north of the Will Knox property where the outcrop pattern indicates steeply plunging isoclinal folds with a wave length of a few hundred feet. In general, small folds (a few feet in wave length) are not as common as in the kyanite quartzite beds at The Pinnacle and Crowders Mountain.

Thin Section Petrology of Sillimanite Quartzite

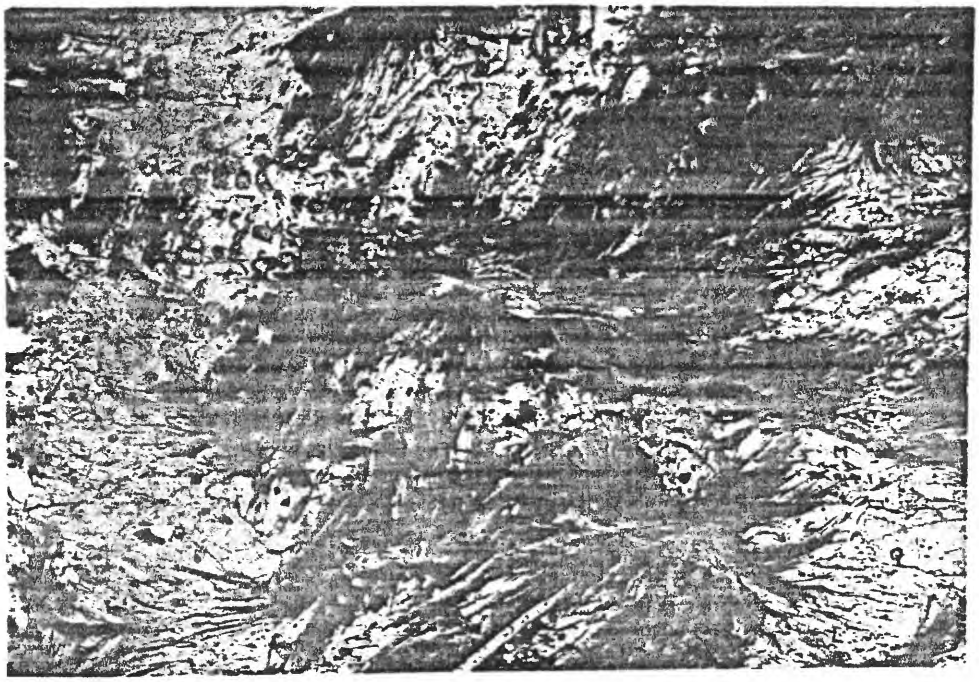
The major constituents of the sillimanite quartzite in both areas are quartz and sillimanite. Andalusite is a common major constituent in the sillimanite quartzite in the vicinity of the Will Knox property and in the quartzite on a small knob 4,400 feet S50E of Reese Mountain. Kyanite also occurs in the quartzite at these localities and is usually less abundant than either sillimanite or andalusite. The occurrence of these three polymorphs in the same rock is described under a separate heading below. Other major constituents in the sillimanite quartzite, although of only local occurrence, are lazulite, diaspore, chloritoid and topaz.

Common accessory minerals include rutile, mica, magnetite, and pyrite. Rare accessories include lazulite, apatite, and zircon.

The typical occurrence of sillimanite is as small (a few millimeters) matted aggregates of very fine fibrolite (Figure 27). The individual prisms of fibrolite are generally 0.04 and 0.2 millimeter long and from about .000Xto .004 millimeter (estimated) wide. Many are

Figure 27. Photomicrograph of sillimanite quartzite. Sample from Ryan-Purcley property. Typical occurrence of fibrolite (F). Other minerals are quartz (Q) and mica (M). Note occurrence of few coarse prisms of sillimanite. Plain light, X 25.

Figure 28. Photomicrograph of andalusite-sillimanite quartzite. Sample from Will Knox property. Andalusite (A) occurs as highly poeciloblastic anhedra; coarse grained sillimanite (S) has partially replaced andalusite; small cross fractures in sillimanite are filled with clay; Q = quartz. Crossed nicols, X 25.



smaller than the resolution of the high power objective. These bundles and radiating matts of fibrolite are commonly flattened and define a good foliation. In many sections the bundles form continuous pinching and swelling seams of fine fibrolite; and not uncommonly small radiating "suns" of fibrolite are set at random in the quartz groundmass. All the fibrolite aggregates finger out intimately into the quartz groundmass with the result that the quartz in the groundmass holds abundant fine hair-like inclusions of sillimanite. This intimate intergrowth of fibrolite and quartz is extremely deleterious as far as the economic recovery of sillimanite is concerned.

In addition to small matts and aggregates of fibrolite, sillimanite also occurs as well defined prisms generally from .05 to 0.9 millimeter wide and up to 2 millimeters long. Some bundles of coarse sillimanite are 1 centimeter long. This coarser grained sillimanite is generally much less abundant than the fibrolite. The two are seen to be intimately intergrown and grade into each other.

The sillimanite content in sillimanite quartzite was estimated in the field to vary from about 10 to 35 per cent. The weight percentages of minerals, calculated from the chemical analysis (see Table VII) indicates a sillimanite content of 33.4 per cent at Reese Mountain, and a combined sillimanite-andalusite content of 39.4 per cent at the Will Knox property.

The quartz groundmass consists of fine, medium or inequigranular grains with inclusions of rutile, mica and sillimanite.

Andalusite, where present, occurs as coarse (1 to 4 millimeters) anhedra, with quartz inclusions. At the Will Knox property, it constitutes from about 2 to 10 per cent and, locally, as much as 60 per cent

TABLE VII

Chemical analyses and calculated mineral percentages of sillimanite quartzite from the Will Knox property, Gaston County, North Carolina (1,1a), and Reese Mountain, Lincoln County, North Carolina (2,2a).

1.		1a.		2.		2a.	
SiO_2	69.59	Quartz	53.8	SiO_2	75.33	Quartz	61.9
Al_2O_3	27.24	Andalusite and Sillimanite	43.1	Al_2O_3	23.36	Sillimanite	36.4
Fe_2O_3	.17			Fe_2O_3	.04	Rutile	.42
FeO	.13	Rutile	1.46	FeO	.18	Magnetite	.2
MgO	.01		98.36	MgO	.01		98.92
CaO	.17			CaO	.01		
Na_2O	.00			Na_2O	.02		
K_2O	.00			K_2O	.10		
H_2O-	.01			H_2O-	.02		
H_2O+	.58			H_2O+	.19		
TiO_2	1.46			TiO_2	.60		
CO_2	.02			CO_2	.02		
P_2O_5	.33			P_2O_5	.06		
S	.03			S			
MnO	.00(tr)			MnO	.00(tr)		
	99.74				99.94		
Less O for S	.01						
	99.73						

1. Chemical analysis of sillimanite quartzite from lens at the crest of hill at the Will Knox property, 0.9 miles N12W of Trinity Church, Gaston County, North Carolina. Analysis made from sample consisting of six specimens taken across the strike of the lens. Analyst: Lucille N. Tarrant, U.S. Geological Survey.

1a. Weight percentages of minerals calculated from chemical analysis, column 1. Mineralogy based on thin section study.

2. Chemical analysis of sillimanite quartzite from lens at crest of Reese Mountain, Lincoln County, North Carolina. Sample a composite of six specimens taken across strike of lens. Analyst: Lucille N. Tarrant, U.S. Geological Survey.

2a. Weight percentages of minerals calculated from chemical analysis, column 2. Mineralogy based on this section study.

of the sillimanite quartzite. It is sometimes penetrated by numerous random matts of fibrolite and coarser sillimanite prisms (Figure 28).

Diaspore occurs locally in fine grained massive aggregates of fibrolite (see below), and in sillimanite quartzite with kyanite and andalusite at the Will Knox property. Here it constitutes about 15 per cent of one thin section, occurring as small ragged anhedra and medium to coarse grained radiating bladed aggregates. It is commonly surrounded by a thin sheath of micaceous aggregate. Small fingers of diaspore penetrate some andalusite grains and diaspore has apparently replaced andalusite pseudomorphically in some cases. Diaspore appears to have developed later and at the expense of kyanite.

Chloritoid occurs in one thin section of the magnetite-bearing sillimanite quartzite from the Ryan-Purcley property. The grains are small, anhedral, and generally ragged. They appear to have been partially replaced by mica, quartz, and sillimanite.

Topaz constitutes about 2 per cent of one thin section of sillimanite quartzite from the Ryan-Purcley property. It occurs as small anhedra and aggregates of anhedra scattered through the quartz groundmass. It holds fine grained inclusions of rutile and is penetrated locally by prisms of sillimanite.

Rutile is the most widespread accessory mineral. It occurs as very fine grained randomly scattered euhedral inclusions in quartz, sillimanite, and andalusite. Coarser grained anhedra (up to 0.6 millimeter) are also common in many thin sections. One crystal of rutile, measuring one and one half centimeters, was found in the sillimanite quartzite at the Ryan-Purcley property. Thin section study and chemical analyses (Table VII) indicate a rutile content of about 1 per cent by weight.

Mica was estimated from thin sections to constitute up to about 2 per cent of the rock. Some of the quartzites carry up to 10 to 15 per cent mica but these have been mapped as schist. Mica occurs generally as small (less than one and one half millimeters) random porphyroblasts; coarse grained porphyroblasts of mica are characteristic of septa of sillimanite quartzite. These flakes have an optic angle of 35 to 40 degrees and are probably muscovite. The very low K_2O and Na_2O content of the sillimanite quartzites indicates a very low mica content. Much of the minor fine grained micaceous aggregate which surrounds some of the minerals such as diaspore and kyanite may be pyrophyllite.

The distribution of magnetite is very sporadic. The chemical analyses indicate a very low magnetite content (a few tenths of one per cent), although field estimates indicate magnetite to constitute 2 per cent of the quartzite locally. Magnetite occurs as small to large anhedral to euhedral crystals disseminated in the quartzite; occasionally magnetite is smeared out along foliation planes.

Fine grained pyrite occurs locally in the sillimanite quartzite south of the Ryan-Purcley property, and north of the Will Knox property. It is less abundant than magnetite and far less abundant than pyrite in the kyanite quartzites of both areas.

Fine grained anhedral lazulite occurs in several thin sections of the sillimanite quartzite. It occurs as small inclusions in sillimanite, and in the groundmass. In one thin section of andalusite-sillimanite quartzite from the Will Knox property, lazulite occurs as rather coarse anhedra interstitial to the quartz. It is intergrown with a colorless mineral, also interstitial, with the following optical properties: -2V, small to moderate; length slow; birefringence = 0.20, relief same as lazulite. The intimate relation of this mineral with pleochroic blue lazulite suggests that it is perhaps colorless lazulite or a related phosphate. The sillimanite near these interstitial aggregates is altered to clay.

Minor amounts of fine grained apatite occur in sillimanite quartzite at the Will Knox property; coarse grained apatite occurs locally in sillimanite quartzite southeast of Reese Mountain. Zircon occurs as a few very small scattered euhedra and anhedra in many of the thin sections.

Table VII gives chemical analyses of sillimanite quartzite from Reese Mountain and the Will Knox property. The weight percentages of the major minerals were calculated from the chemical analyses, taking into account the mineral phases identified in thin section. It is believed that this is the most accurate way to calculate the percentage of sillimanite in that sillimanite is very fine grained and intimately intergrown with quartz. The small (.58 per cent) water content of the sillimanite quartzite from the Will Knox property reflects the minor, yet widespread, incipient alteration of sillimanite and andalusite to clay. This is noticeable in thin sections and in the field. Thin veins of clay commonly cut the rock and in some cases clay forms partial or complete pseudomorphs after sillimanite. Massive aggregates of fibrolite (see below) are commonly replaced by clay.

Massive Aggregates of Fibrolite

Small pieces of float of massive aggregates of fibrolite occur at the Ryan-Purcley property, at the Will Knox property, at Reese Mountain, and along the contact of the Yorkville granodiorite. This rock occurs in only minor amounts. The rock generally weathers to smooth rounded boulders and cobbles. It is extremely tough. Fine grained random swirling matts and aggregates of fibrolite, and minor amounts of coarser grained prismatic sillimanite constitute about 90 to 99 per cent of the rock. Rutile and mica are common accessories. Other minerals present in this rock are quartz, magnetite, zircon, diaspore, andalusite, tourmaline and biotite.

The quartz occurs as fine and coarse grained anhedral aggregates, sometimes with andalusite. Diaspore constitutes up to about 50 per cent of one thin section of rock from the Ryan-Purcley property and about one to 2 per cent of thin sections of rock from the north slope of Reese Mountain. In both cases diaspore is altered along cleavages and fractures to a fine grained micaceous aggregate. In the thin section from Reese Mountain diaspore is seen to cut across bundles of fibrolite and apparently replace fibrolite along prism boundaries. In the thin section from the Ryan-Purcley property, fine matts of sillimanite penetrate and cut across diaspore. The evidence of paragenesis in this thin section is inconclusive— the two high alumina minerals may have developed at about the same time.

In many thin sections, fibrolite is seen to have been partially or completely pseudomorphically altered to clay. Such pseudomorphic replacement of fibrolite has also been noted in the rocks at Williamstown, Australia (Alderman, 1948). This Australian clay has been identified as being largely kaolinite with some dickite.

Andalusite Rock

A distinctive massive, coarse grained, gray rock, consisting of about 65 to 95 per cent andalusite, occurs at two localities in the vicinity of the Will Knox property. It occurs between two sillimanite quartzite lenses southeast of Will Knox' house, and also between the kyanite quartzite bed and sillimanite quartzite bed north of the Will Knox property. These occurrences, both being between two beds or lenses of quartzite, suggest a stratigraphic correlation.

The andalusite occurs as coarse grained crystals up to one and one half centimeters across. Most are from 3 to 4 millimeters across. On the weathered surface, these crystals show clean faces, unaltered by mica or clay. In thin section, the other major constituents are seen to be sillimanite (3 to 5 per cent), quartz (3 to 30 per cent) and magnetite (2 to 3 per cent). Muscovite occurs as an accessory. The sillimanite, which in hand speciman is seen as thin white matts, is seen in thin section to be matts of fibrolite and coarser prisms interstitial to the coarse grained andalusite. This interstitial distribution, and the fact that sillimanite prisms penetrate the coarse grained andalusite suggest that sillimanite developed later than andalusite.

Andalusite-Kyanite-Sillimanite Quartzite

The three polymorphs of Al_2SiO_5 occur together in seven thin sections of quartzite from widely separated localities in both the Kings Mountain-Henry Knob and Reese Mountain-Clubb Mountain areas.

In the Kings Mountain-Henry Knob area they occur together in the sillimanite quartzite lenses at the extreme north and south ends of the Will Knox property. In the Reese Mountain-Clubb Mountain area they occur on the crest and north slope of a small conical hill 4,400 feet S50E from the crest of Reese Mountain; and at the small hillock 1,200 feet N35E of the crest of Reese Mountain.

The field relations indicate little about the paragenesis. Local concentrations of kyanite occur in quartzite at the Will Knox property and at the hill southeast of Reese Mountain. At the latter locality veins of kyanite cut the quartzite.

The major constituents of the quartzite, in which the three polymorphs occur together, are quartz, sillimanite, andalusite, and kyanite. Diaspore is abundant in one thin section of rock in which kyanite is also abundant. Accessory minerals include mica, rutile, and lazulite.

The high alumina minerals (including diaspore, when present) constitute up to 60 per cent of the rock. The polymorphs rarely occur in equal amounts: kyanite and andalusite, or sillimanite and andalusite are the two most abundant pairs; kyanite rarely occurs in abundance with sillimanite. The following summary indicates the paragenetic relation between the three polymorphs.

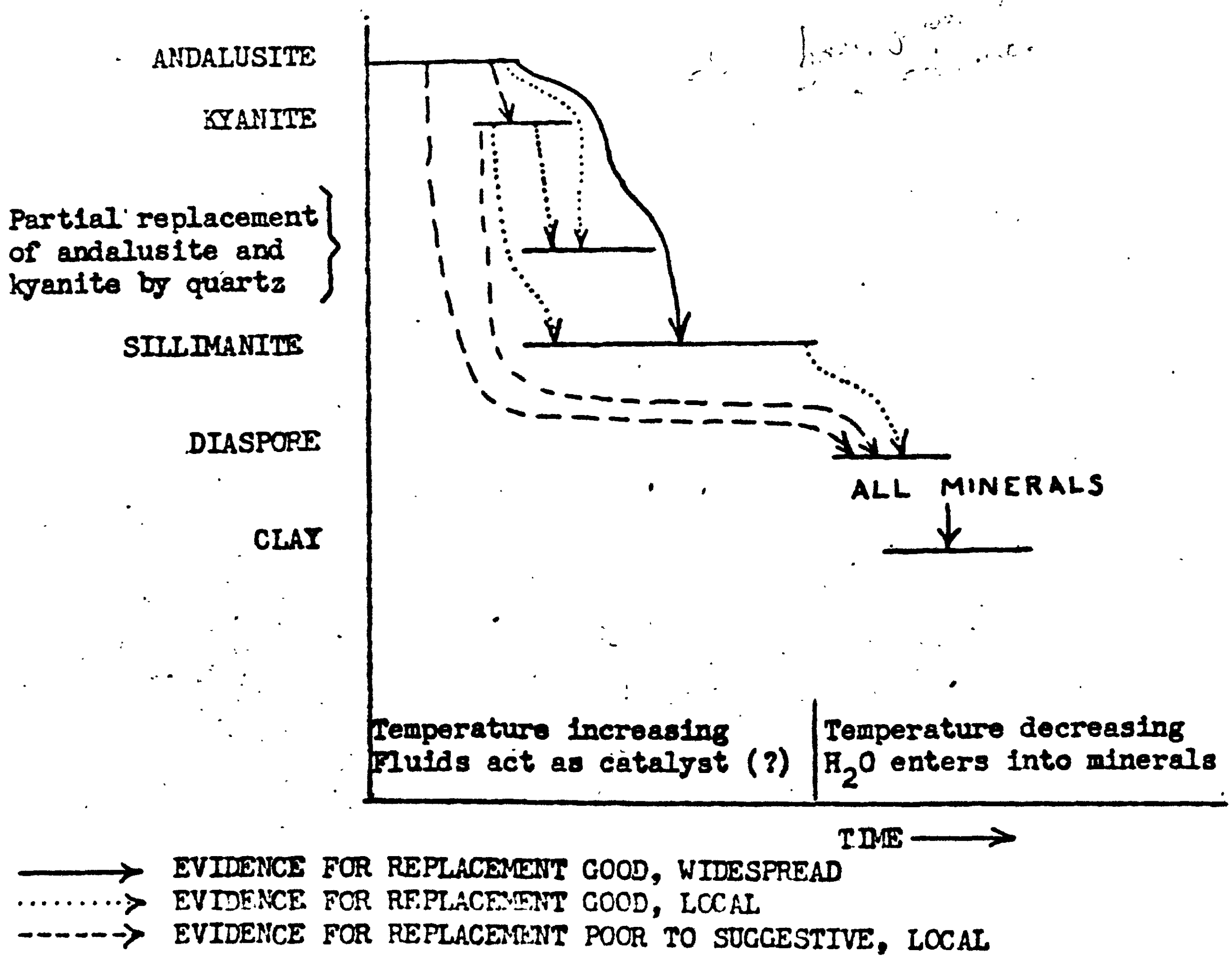
Andalusite-kyanite relationship: in most thin sections a few kyanite blades are set at random in coarse grained andalusite porphyroblasts and there are no features diagnostic of paragenesis. In one thin section, however, kyanite appears to have pseudomorphically replaced coarse grained (2 to 4 millimeters) rectangular andalusite crystals. In this case random kyanite blades occur within the euhedral andalusite crystals; kyanite is sometimes so abundant that only small optically oriented remnants of andalusite remain within the rectangular outline of the original crystal.

The development of kyanite later than, and apparently at the expense of, andalusite is also seen in some of the staurolite-chloritoid-kyanite quartzites (see Kyanite Quartzite). Kyanite has pseudomorphically replaced a coarse grained columnar mineral with square cross section (probably andalusite) at Jefferson Mountain, 16 miles southeast of the Will Knox property.

Andalusite-sillimanite relationship: andalusite occurs typically as coarse grained poeciloblastic crystals. In several cases these porphyroblasts have been partially replaced by quartz as evidenced by irregular quartz embayments into andalusite, and the isolation of andalusite into parallel and optically oriented remnants separated by quartz. Sillimanite commonly occurs as fine grained prisms in the quartz that has replaced andalusite; also sillimanite prisms project into the margins of andalusite crystals (Figure 28), and occur as random matts within andalusite. The fact that sillimanite prisms project into andalusite may indicate that sillimanite had a greater tendency to develop euhedral crystals (i.e. greater form energy: Ramberg, 1952, p. 131) than andalusite. If such is the case the two minerals may have developed simultaneously. However, the fact that sillimanite is intimately intergrown with quartz that has replaced andalusite suggests that sillimanite developed later than andalusite. The mobility of sillimanite material late in the metamorphic period is convincingly shown in two cases by the thin intestine-like veins of fibrolite aggregates that cut the quartzite.

Sillimanite-kyanite relationship: Locally, sillimanite occurs intimately intergrown with quartz that has replaced kyanite. The kyanite in some thin veins (in the quartzite lens southeast of Reese Mountain) has been partially replaced by fibrolite; in this case fibrolite aggregates are seen to cut across kyanite blades. The most clear cut evidence of an age relation between kyanite and sillimanite comes from a rock found on the east slope of Henry Knob. In this case swirling matts of fibrolite penetrate kyanite and isolate optically oriented islands of kyanite from large kyanite blades.

The general paragenetic sequence of high alumina minerals associated with the sillimanite quartzite is summarized below. It must be stressed that this age relation holds for only those local cases in which two or more polymorphs occur together. While it is risky to correlate such evidence from widely separated localities, the sequence of replacement may be significant in indicating a regional sequence in metamorphism. The effect of temperature and fluids are discussed under Metamorphism.



Rocks Associated with Sillimanite Quartzite (see also Quartz-Mica Schist, Biotite Gneiss and Schist, Schistose Pyroclastic Rock)

The following schists and gneisses are in contact, or occur in the immediate vicinity of sillimanite quartzite. They are listed in order of abundance

(1) Quartz-mica schist (with or without traces of garnet, andalusite or sillimanite)

(2) Quartz-biotite schist, biotite gneiss (with or without garnet and/or sillimanite)

(3) Schistose pyroclastic rock (with or without sillimanite)

IGNEOUS ROCKS

Yorkville Granodiorite

Introduction

This rock, named the Yorkville Granite by Keith and Sterrett (1931), consists of several related varieties, of which the most widespread is a medium to dark gray, coarse, porphyritic, usually gneissoid granodiorite*.

While the present report represents the most detailed field and petrographic study of the Yorkville granodiorite to date, it must be stressed that observations were restricted to about a mile-wide strip adjacent to the contact with the older metamorphic rocks. Thus, in the Kings Mountain-Henry Knob region, the mapping included one small area about two miles west of Clover, York County, South Carolina, and an eight mile belt along the western contact from the upper reaches of Beaverdam Creek, two miles north of Clover, to Crowders Creek, Gaston County, North Carolina. In the Reese Mountain-Clubb Mountain area, the eastern contact between the granodiorite and the metamorphics was mapped in an arcuate belt extending from one mile west of Stanley Creek north about eight miles to the vicinity of Machpelah Curch. The overall extent of the Yorkville granodiorite is unknown. Available data (Figure 1) indicate it is a large body covering the southeastern part of the Kings Mountain Quadrangle and an unknown, but probably large portion of the Clover Quadrangle to the east. It narrows northward in the Gastonia

* Classified according to Johannsen (1932).

Quadrangle to a width of about two and one half miles. Keith and Sterrett (1931) indicate that it crops out over a large area in the Sharon Quadrangle south of the Kings Mountain Quadrangle, and reconnaissance work by Keith and Sterrett* indicates that it extends at least 18 miles north of the northern boundary of the Gastonia Quadrangle in the Hickory Quadrangle. Thus, the Yorkville granodiorite appears in this region to be a very large body or series of bodies of variable width trending north-northeast over a distance of more than 55 miles.

Description

The following related varieties of the Yorkville granodiorite are distinguished: (1) coarse, porphyritic, usually gneissoid biotite granodiorite and quartz monzonite, by far the most abundant variety; (2) medium grained, slightly porphyritic biotite quartz monzonite and granodiorite gradational in the field with variety 1; (3) fine to medium grained, non-porphyritic, gneissoid biotite granite and quartz monzonite; and (4) coarse, porphyritic hornblende granodiorite. Because of the subtle gradation between them, the first two varieties were mapped as one unit in the field; varieties 3 and 4 occur only in minor amounts and were also combined with the first variety as one unit.

(1) The coarse, porphyritic variety of the Yorkville granodiorite generally has a gneissoid structure and, in a few places, a steeply plunging lineation produced by the parallel orientation of large microcline phenocrysts as well as biotite aggregates in the groundmass. The phenocrysts are commonly one half to one inch long and some have a maximum length of two inches (Figure 29). They generally exhibit carlsbad twinning and vary from euhedral to rounded anhedral forms. Fine grained,

* Keith, Arthur, and Sterrett, D. B., Unpublished reconnaisance map of the southeastern corner of the Hickory Quadrangle.

randomly oriented flakes of black biotite, in very minor amounts, are embedded in the phenocrysts.

In contrast to these large, light yellowish gray microcline phenocrysts which constitute up to 25 per cent, but average 19 per cent of this variety, the groundmass consists of medium grained gray quartz, light gray to white oligoclase, and black biotite, all major constituents. Muscovite, constituting about 2 per cent of the rock, occurs as well formed flakes and ragged, wormy intergrowths with biotite. Myrmekite and fine grained interstitial aggregates of sodic oligoclase or albite constitute about 5 per cent of this variety. Accessory minerals, taken together, make up slightly more than 1 per cent. They include zircon, epidote, apatite, sphene, magnetite, pyrite and allanite. At two different localities, each within 200 feet of the main contact or metamorphic septa, kyanite, sillimanite, staurolite, and rutile were recovered by panning the highly weathered granodiorite.

The mineralogy of the feldspars is complex. The microcline phenocrysts are generally microperthitic, the included albite occurring in only very minor amounts (generally less than 5 per cent of the phenocryst) as very fine grained discontinuous shreds and small, irregular discontinuous random grains that pinch and swell. These grains are generally less than 0.09 millimeter in greatest dimension. In many phenocrysts the very fine shreds and some elongate irregular grains of albite are parallel to each other and at the same time may be either parallel to or transect the microcline twin lamellae. Fine shreds of albite transect the carlsbad twinning plane of one phenocryst. These features, in addition to the random orientation of much of the fine grained ragged albite, appear to indicate a replacement origin for the albite in the perthite. However, there are two features that apparently contradict this and indicate that some of the small irregular patches of albite may have formed by exsolution. Some microcline phenocrysts are zoned. In these, the core, which does not extinguish with the outer margin of the phenocryst, has very closely spaced thin twin lamellae. These cores are probably anorthoclase. More fine grained albite occurs in these cores than in the microcline borders, suggesting that the sodium for the albite has been derived from the more albitic host. Moreover, the total amount of albite forming microperthite in any one unzoned phenocryst appears to be fairly constant. Thus, some areas have fine, closely spaced shreds of albite while adjacent areas in the same phenocryst have more widely spaced coarse, discontinuous grains of albite, the total amount of albite in either area being approximately the same.

The microcline phenocrysts generally carry minor amounts of fine grained rounded quartz grains, fine grained flakes of biotite, and small grains of oligoclase. The oligoclase grains are generally rounded or have smooth grain boundaries; they are generally 0.3 millimeter or less in diameter. A few transect carlsbad twin planes in the microcline and others have a somewhat ragged rectangular pattern that conforms to the grid twinning planes. These small grains of oligoclase are nearly always surrounded by a fairly wide rim of albite. Several grains have an incomplete narrow band of myrmekite between the oligoclase and the other rim of albite. This sequence on a minor scale reflects the myrmekite development seen on a larger scale and described below. The curious feature here is that the albite rim about the oligoclase grain is from one quarter to one third the width of the grain, while albite

Figure 29. Hand specimen of typical coarse grained porphyritic Yorkville granodiorite (Variety 1). Sample from quarry, 0.9 mile southwest of Machpelah Church. The phenocrysts are largely microcline, with some oligoclase; dark mineral is biotite. Scale is graduated in inches.

Figure 30. Photomicrograph of coarse grained Yorkville granodiorite. Sample of road construction metal near Trinity Church. Microcline phenocryst (M), oligoclase (O), quartz (Q), biotite (B). Note myrmekitic margin on oligoclase crystal in contact with microcline but no myrmekitic margin when this crystal is in contact with other oligoclase crystals. Crossed nicols, X 25.


2 3 4 5 6 7 8
CROWN CITY LUMBI

rims about the major zoned plagioclase crystals throughout the rock are not nearly this wide.

It is not certain whether the small oligoclase grains are inclusions of an earlier phase in microcline, a phenomenon of replacement, or the result of more or less simultaneous crystallization. They have the appearance of inclusions, and the extraordinary thickness of the albite band suggestsaccretion of albite by exsolution from the microcline.

Plagioclase, which generally makes up 22 to 37 per cent of the rock, occurs as weakly to strongly zoned subhedral to euhedral crystals about 1.5 to 5 millimeters in greatest dimension. In one thin section the plagioclase cores are andesine, An.38,and the outer margins are oligoclase, An.25. In ten thin sections the range of the most calcic portions of the plagioclase is between An.24 and An 30. Some crystals are completely gradational from the core to the sodic oligoclase rims, while many have a rather sharply defined overgrowth of sodic oligoclase, An.15,to albite, An 7.

The coarse grained microcline and plagioclase crystals are generally surrounded by an interstitial aggregate consisting of anhedral sodic oligoclase or albite, myrmekite, quartz, biotite, and, rarely, orthoclase.

When in contact with microcline phenocrysts, the sodic oligoclase margins of large plagioclase crystals are myrmekitic (Figure 30). Myrmekite is also developed when oligoclase in the interstitial aggregate is in contact with microcline phenocrysts, the typical contact being a broad tongue-shaped embayment of myrmekite into microcline. A thin rim of albite is generally present about the outermost portion of these tongues. Myrmekite is not, however, restricted to sodic oligoclase in contact with microcline. It also occurs, to a minor extent, as rather discrete anhedra in the interstitial aggregate. The myrmekitic embayments into microcline from the interstitial aggregate, and especially the myrmekitic embayments from the adjacent oligoclase crystals, indicate that myrmekite here is a replacement or reaction phenomenon and not, as Spencer (1945) indicates for some British granites, a phenomenon of exsolution from the microcline crystal.

In most of the thin sections plagioclase is slightly antiperthitic, with small randomly distributed grains and patches of microcline scattered through the larger oligoclase hosts. Some irregular elongate grains of microcline transect the albite twin lamellae in the host. It is not obvious whether this microcline has resulted from exsolution or replacement.

In summary, the feldspars exhibit perthitic and antiperthitic textures, the origin of which is not certain from this study. Two generations of microcline are evident: an earlier phenocrystic stage in which some of the cores of the phenocrysts are probably anorthoclase and a later stage in which the microcline occurs in an interstitial aggregate. The plagioclase feldspars are commonly strongly zoned, the outer portions of many crystals being overgrowths of sodic oligoclase or albite. The simplest explanation of these overgrowths and also the myrmekitic and non-myrmekitic oligoclase and albite in interstitial aggregates is that strong fractionation in a large body of magma resulted in an albite-rich late fraction.

Quartz occurs as anhedral grains, generally intermediate in size between the zoned plagioclase crystals and the fine grained interstitial aggregate. The grain boundaries are smooth to irregular but show no suturing and the grains are characteristically free from inclusions and strain shadows.

Biotite flakes are pleochroic from pale brown to very dark brown, (- 2V very small, n_γ = 1.638). Small inclusions of apatite and zircon are common. Frequently the flakes occur in elongate aggregates interstitial to the larger oligoclase crystals and microcline phenocrysts. Muscovite occurs as individual flakes or parallel intergrowths with biotite and also as ragged wormy growths usually in plagioclase.

Zircon occurs generally as euhedral, elongate, doubly terminated prisms up to 1 millimeter long. Epidote occurs as discrete anhedral crystals to about 0.5 millimeter across. In most of the thin sections epidote occurs as an overgrowth about small, yellowish, euhedral zoned allanite cyrstals. The degree of metamictization of allanite varies from crystals that are completely isotropic to those that show low interference colors and well defined twinning but no pleochroism. Rarely allanite occurs without an overgrowth of epidote. Apatite occurs as randomly distributed subhedral and euhedral crystals. Sphene varies from anhedral to euhedral but generally occurs as coarse subhedral to euhedral crystals up to 1.8 millimeter long. Small anhedral to euhedral crystals of ilmenite and pyrite occur in all thin sections.

All of the varieties of the Yorkville granodiorite seen in thin section are characteristically only slightly altered. The plagioclase cores (including both the major coarse grained crystals of oligoclase and the few small inclusions of oligoclase in the microcline phenocrysts) are commonly slightly to moderately altered to fine grained random flakes of clear mica, and small amounts of clay. Microcline phenocrysts and fine grained microcline are unaltered. A few thin sections show a white feathery alteration product (leucoxene ?) around ilmenite and biotite. Calcite occurs locally as an alteration product of plagioclase.

Table VIII gives chemical and modal analyses of Variety 1 of the Yorkville granodiorite. The most representative mode is given in Column 5 which is the average of six thin sections from widely separated outcrops in both the Kings Mountain-Henry Knob and Reese Mountain-Clubb Mountain regions. In each section 1,000 points were counted in the groundmass. The relative abundance of potash feldspar phenocrysts was determined by making linear measurements on the hand-specimens.

The agreement between the calculated chemical composition (Column 3) and the chemical analysis (Column 2) of samples from the Lincoln County quarry is good. One significant chemical feature of the rock is its low MgO content in view of the fact that the rock here contains 8 per cent biotite. The index of refraction of the biotite indicates it to be an intermediate variety between the phlogopite-eastonite and annite-siderophyllite groups (Winchell, 1951, p. 374).

(2) The light gray, medium grained, slightly porphyritic variety of the Yorkville granodiorite is identical in mineralogy with Variety 1 but differs from it in having a fine to medium grained groundmass and fewer and smaller phenocrysts. The phenocrysts here are

TABLE VIII

Chemical and modal analyses of Variety 1 of the Yorkville granodiorite

	1.	2.	3.	4.		5.	
SiO_2	70.77	71.55	70.01	Calcic oligoclase	33	Calcic oligoclase	31
Al_2O_3	14.89	14.47	15.08	Microcline	20	Microcline	21
Fe_2O_3	.75	.46	2.81	Quartz	30	Quartz	27
FeO	1.24	1.51		Biotite	8	Biotite	11
MgO	.43	.77	.87	Myrmekite	2	Myrmekite	2
CaO	2.08	2.00	2.25	Albite and		Albite and	
Na_2O	4.47	3.72	3.58	sodic oligoclase	4	sodic oligoclase	4
K_2O	4.70	4.16	4.37	Muscovite	2	Muscovite	2
H_2O-		.02		Epidote	0.2-0.7	Epidote	0.2-0.9
H_2O+		.34	.45	Sphene	0.1-0.2	Sphene	0.0-0.9
TiO_2	.36	.40	.48	Apatite	0.1-0.2	Apatite	0.0-0.2
CO_2		.23		Ilmenite	0.4-0.5	Ilmenite	0.0-0.5
P_2O_5	Trace	.13	.07	Zircon	0.2	Zircon	0.0-0.4
MnO	Trace	.06		Allanite	0.1	Pyrite	0.0-0.1
Ignit.	.19					Allanite	0.0-0.1
	99.88	99.82	100.23				

1. Chemical analysis of rock at Whitesides quarry, 3 miles west of Filbert Station, York County, South Carolina. Watson (1910, p. 207).

2. Chemical analysis of coarse grained porphyritic granodiorite (Variety I of the Yorkville granodiorite). Sample was a composite of six hand specimens from small quarry 0.9 miles southwest of Machpelah Church, Lincoln County, North Carolina. Analyst: Lucille N. Tarrant, U.S. Geological Survey.

3. Chemical composition calculated from mode, column 4.

4. Mode of coarse grained porphyritic granodiorite from small quarry 0.9 miles southwest of Machpelah Church, Lincoln County, North Carolina. Average of three sections, two of which came from samples used for chemical analysis given in column 2.

5. Mode of coarse grained porphyritic granodiorite. Average of six sections from Kings Mountain-Henry Knob and Reese Mountain-Clubb Mountain regions.

generally not over 1 centimeter long and constitute from 2 to 6 per cent of the rock.

Anorthoclase cores in microcline phenocrysts are abundant in several sections of this variety. Although the relative abundance of microcline phenocrysts is less in this variety than in Variety 1, the ratio of potash feldspar to plagioclase in each section still places the various samples in either the quartz monzonite or granodiorite family. The groundmass of this variety contains much more microcline than the groundmass of Variety 1. Microcline occurs as isolated anhedral crystals and also as irregular, poorly defined interstitial aggregates.

It is interesting to note that this medium grained, slightly porphyritic variety of the Yorkville granodiorite was found at two principal localities: (1) at the northern termination of a portion of the coarse porphyritic variety of the Yorkville granodiorite, 2 miles west of Clover, York County, South Carolina, and (2) one quarter square mile embayment from the margin of the coarse porphyritic variety, 2 miles southwest of Machpelah Church, Lincoln County, North Carolina. This distribution suggests that the slightly porphyritic variety (2) may be the chilled equivalent of Variety 1.

(3) The fine grained, equigranular, gneissoid granite and quartz monzonite occurs as a narrow, gradational zone in the coarse porphyritic variety 0.3 mile north of Pisgah Church, as a border facies west of the coarse porphyritic contact 2 miles east of Henry Knob, and as an isolated outcrop within, and apparently conformable with the metamorphic rocks 1.6 miles northeast of Henry Knob.

Microcline is much more abundant than oligoclase in the granite, and myrmekite occurs only in minor amounts. In addition, thin sections of this composition contain no sphene nor zircon but do have abundant accessory magnetite and apatite, and a little epidote and pyrite. Well formed flakes of muscovite are intergrown with biotite and sometimes exceed biotite in abundance. Such mineralogy is indicative of a later magmatic fraction than the mineralogy of Variety 1.

(4) Hornblende granodiorite is coarse grained slighly porphyritic and usually strongly gneissoid. It occurs locally southeast of Trinity Church where it is gradational with Variety 1. The plagioclase is usually more calcic than that of Variety 1, the cores of some crystals being andesine, An 33 . Biotite is much more abundant than in Variety 1. The thin section has the following mode:

calcic oligoclase	33 per cent
microcline	11 per cent
quartz	18 per cent
biotite	20 per cent
hornblende	6 per cent
epidote	3 per cent
myrmekite, albite or sodic oligoclase	per cent
sphene	3 per cent

accessory muscovite, magnetite and zircon .

Dike Rocks Cutting the Yorkville Granodiorite

Quartz Monzonite and Granodiorite

At several localities in the Kings Mountain-Henry Knob area, small, irregular bodies and dikes of medium grained, equigranular quartz monzonite and granodiorite cut the coarse grained porphyritic granodiorite. The contact between the dike rock and the coarse grained granodiorite sharp and many dikes cut across the gneissoid structure. Although the dike rock is medium grained and equigranular, its mineralogy is strikingly similar to the coarse grained porphyritic granodiorite. The major constituents of the dike rock are calcic oligoclase, An. 26- An. 30, microcline, quartz, biotite, myrmekite and muscovite. Accessory minerals include epidote, magnetite, zircon, and allanite.

Aplite

Small dikes of fine and medium grained granitic aplite are especially abundant near the contact of the main body of the coarse porphyritic granodiorite. The borders of these dikes are sometimes sharp, sometimes gradational with the host. The major mineral constituents are microcline, quartz, calcic oligoclase, An 26, and muscovite. Myrmekite has partially replaced microcline, and occurs with microcline and oligoclase as an interstitial aggregate. Epidote, apatite, and magnetite occur as accessories.

Pegmatite

Cross-cutting pegmatite dikes are very common near the contact of the main porphyritic body. An area of fine grained granite, two miles east of Henry Knob, contains abundant cross-cutting and conformable pegmatite bodies. Some of the conformable bodies have gradational contacts with the granite and commonly have a very gentle dip.

In addition to these pegmatite dikes within the main body of the granodiorite, there are many cross-cutting pegmatite dikes in the hornblende gneiss and biotite schist up to one half mile west of the granodiorite contact in the Kings Mountain-Henry Knob area. These pegmatite dikes range from a fraction of an inch to about a foot in width. Their mineralogy, as well as their proximity to the margin of the pluton, indicates a genetic relation to the Yorkville granodiorite. The major mineral constituents of the pegmatite dikes are microcline (microperthitic), antiperthitic oligoclase An 20-22, and muscovite, with variable, but usually small amounts of myrmekite, albite, biotite apatite and almandine garnet (n = 1.82).

Two of the thin sections of pegmatite show two generations of microcline, an early coarse grained microperthitic phase and a later fine grained interstitial phase. This later phase, to a minor extent, replaces some of the myrmekite.

No kyanite, sillimanite or andalusite was seen in any of these pegmatite bodies.

Nature of the Contact

The contact of the coarse porphyritic variety of the Yorkville granodiorite is, in general, vertical or very steeply dipping, and conformable to the flow cleavage of the adjacent schists and gneisses, but transects some of the metamorphic units at a very low angle. This contact in both the Kings Mountain-Henry Knob area and the Reese Mountain-Clubb Mountain area is generally straight or gently sinuous in plan, with the exception of one large embayment 1 mile north of Reese Mountain. In general, the coarse grained porphyritic granodiorite has a strong gneissoid structure that is parallel to the contact with the metamorphic rocks.

In detail the contact is much more complex than indicated by the straight or gently sinuous contact on the geologic maps (Plates I and II).

The contact in the area east of Henry Knob is particularily complex in plan. Keith and Sterrett (1931) show a large body of "Yorkville granite" interfingering with hornblende gneiss southeast of Henry Knob. An isolated outcrop of slightly porphyritic Yorkville granite (Variety 3) occurs 1.6 miles northeast of Henry Knob. This apparently represents a small conformable isolated intrusion into the metamorphic rock. Between this outcrop and the main body of the granodiorite to the east, the quartz biotite schists and gneisses are intercalated with narrow bodies of fine grained non-porphyritic granite (Variety 3); cross-cutting and conformable pegmatite bodies are abundant in this area. Some of the conformable pegmatite bodies have gradational contacts with the fine grained gneissoid granite.

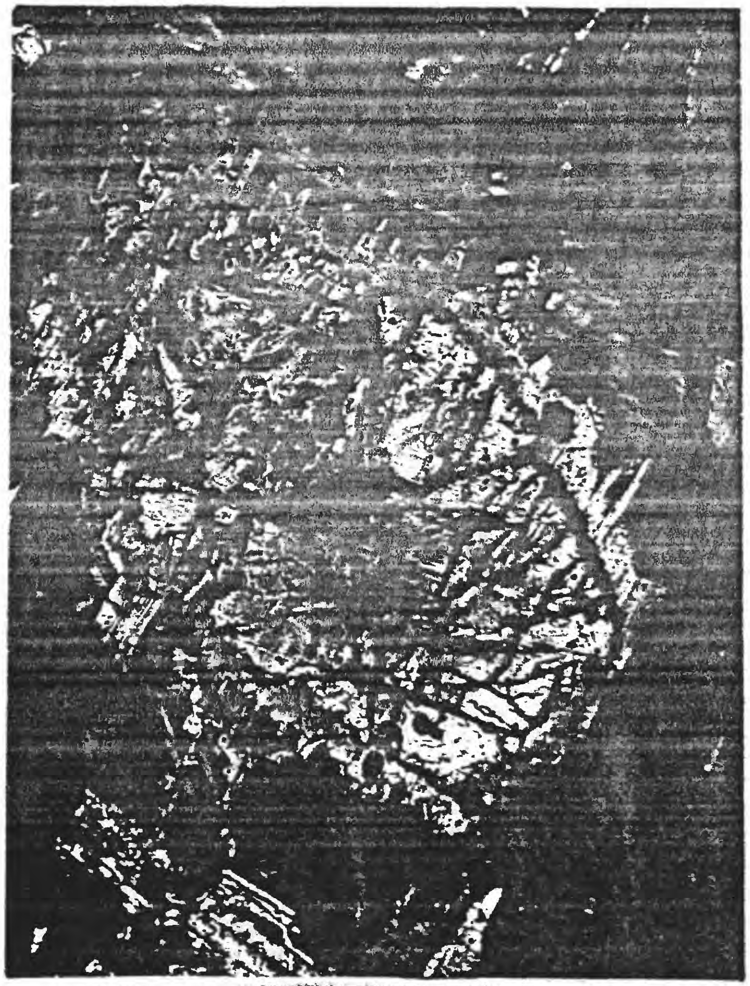
Septa

Numerous long, narrow, steeply dipping septa, consisting of various types of schists, gneisses, and hornfels, occur in the coarse grained porphyritic Yorkville granodiorite within three-quarters mile of its contact with the metamorphic rocks. Individual septa are about 2 to 50 feet wide and can be traced along strike for several hundred feet. A single septum of sillimanite schist extends for about one mile along strike. The septa are generally parallel to the gneissoid structure in the granodiorite. The contact between the septa and the granodiorite is generally abrupt. The following rock types were found as septa:

1) sillimanite-muscovite schist, sillimanite quartzite and conglomerate.

2) corundum-bearing gneiss,

Figure 31. Photomicrograph of Corundum gneiss. Sample from septa in granodiorite 1.3 miles northwest of Pisgah Church. Large centered crystal is corundum, surrounded by a rim of muscovite. Note grid twinning in microcline that makes up most of the remainder of photograph. Crossed nicols, X 65.



3) biotite gneiss with variable amounts of garnet and sillimanite,

4) garnet-quartz-biotite schist,

5) manganiferous schist and fine grained spessartite rock,

6) pyroxene granulite,

7) hornblende gneiss.

Of these types, 1, 3, 4 and 7 are most abundant and have been discussed in connection with similar rocks in the main metamorphic sequence. A discussion of the important aspects of the remaining types follows.

Corundum-bearing gneiss occurs just south of Crowders Creek, about 1000 feet east of the contact between granodiorite and the main body of metamorphic rocks. The corundum-bearing gneiss is a medium-grained massive rock. The estimated modal range, as indicated by three thin sections, is:

muscovite	30 to 90 per cent
microcline	0 to 45 per cent
corundum	1 to 10 per cent
sillimanite	2 to 5 per cent

small amounts of sodic to median oligoclase, biotite and magnetite.

Corundum occurs as corroded euhedral grains up to 1.2 millimeters long (Figure 31). With few exceptions corundum crystals are completely surrounded by a sheath of muscovite that has formed partly at the expense of (corroded) the corundum. A few corundum crystals occur within microcline grains without a sheath of muscovite and for this reason it is thought that the muscovite sheath was a late hydrothermal alteration (corundum + microcline + water → muscovite) and not produced at the time of the growth of the corundum.

Corundum gneiss also occurs as small pieces of float near the contacts between the granodiorite and metamorphic rocks. One large cobble of massive corundum rock was found northwest of Pisgah Church. This rock consists of about 75 per cent corundum, 20 per cent sillimanite, and 5 per cent magnetite. Sillimanite is interstitial to the coarse randomly oriented plates and prisms of corundum. The significance of corundum in septa and inclusions in the Yorkville granodiorite is discussed under Metamorphism.

Manganiferous schist occurs as long, discontinuous lenses in the granodiorite from Crowders Creek south to Chapel Grove School (Figure 1 and Plate I). The alignment of these lenses, and the fact that they occur from 350 to 800 feet east of a long septum of sillimanite schist suggests a single stratigraphic position for the manganiferous schist.

In the field, manganiferous schist is seen to consist principally of sooty, medium grained flakes of mica. Generally, the soil derived from manganiferous schist is strewn with chunks of highly stained very fine grained spessartite rock. Two thin sections of this rock have the following estimated mode:

spessartite	60 to 65 per cent
quartz	20 to 25 per cent
hornblende	10 to 15 per cent

and small amounts of biotite and magnetite.

A distinct layering is produced by hornblende-rich and hornblende-poor bands a few millimeters wide.

Pyroxene granulite occurs as a septum in granodiorite northeast of Trinity Church. The rock is fine grained, medium to dark gray and massive. Three thin sections have the following estimated modal range:

Labradorite, An 57-59	10 to 45 per cent
quartz	20 per cent
pyroxene and uralitic hornblende	5 to 60 per cent
epidote	10 to 30 per cent
hornblende (non-uralitic)	0 to 5 per cent

small amounts of garnet, microcline, magnetite, sphene, and apatite.

Labradorite, quartz, and microcline are seen in thin section to form a very fine grained granulitic groundmass. Pyroxene (probably augite), hornblende, epidote, and garnet occur as coarser grained porphyroblasts. The bulk chemical composition of the rock was calculated from two similar modes with the following results:

SiO_2	55 per cent
Al_2O_3	17 per cent
Iron oxides	8 per cent
MgO	2 per cent
CaO	13 per cent
Na_2O	2 per cent

The most striking features of such a composition are the high alumina content, and combined low magnesia-high lime content. The fine grained granulitic groundmass suggests that the parent rock was a very fine grained sediment and the chemical composition approximates that of some marls.

The following rock types do not occur as septa, but occur only locally as float within the area of exposure of granodiorite. They are included because of their interesting mineralogy.

Cordierite hornfels was found locally as float near Pisgah Church. Fine to medium grained anhedral cordierite makes up about 50 per cent of the rock. Other minerals include andesine, quartz, microcline, and muscovite. Some of the cordierite shows cyclical extinction, and it holds inclusions of zircon which are surrounded by pleochroic haloes.

Anthophyllite gneiss occurs locally as float near Chapel Grove School. In addition to anthophyllite this fine grained gneiss consists principally of andesine and quartz.

General Conclusions on the Septa and Origin of the Yorkville Granodiorite

It is estimated from measurements made on aerial photographs that septa, in any one place where they are particularly abundant, constitute less than 5 per cent of the surface area of the granodiorite. Thus, they are volumetrically relatively unimportant.

The strongly divergent chemical and mineralogical composition of the septa suggests that the septa are remnants of a metasedimentary and metavolcanic sequence (see Structure) and not products of magmatic segregation or late magmatic injection.

Only a limited number of minerals in the septa can probably be attributed to metasomatic sources: interstitial oligoclase and myrmekite, some quartz, and perhaps some muscovite. A review of the mineralogy of the septa shows that these minerals constitute only a minor portion of the various rock types.

There is some evidence that assimilation of the country rock has locally enriched the granodiorite in certain components. Thus, the one outcrop of hornblende granodiorite occurs in the vicinity of hornblende gneiss; and minor traces of kyanite and sillimanite were found near septa of sillimanite quartzite.

A thorough study of the entire Yorkville granodiorite body is needed before its origin can be reasonably well known. In the meantime, the present study reveals several features which, it is believed, indicate that the granodiorite crystallized from a magma.

(1) Dikes of medium grained, non-porphyritic granodiorite cut the main body of coarse porphyritic granodiorite. Both have identical mineralogy. Thus, there is good proof that a granodiorite magma existed at least on a small scale.

(2) The mineralogy of the coarse porphyritic granodiorite (microperthitic microcline, antiperthitic zoned plagioclase, interstitial sodic oligoclase and myrmekite, and allanite) is distinctly different from the mineralogy of any of the metamorphic rocks. This mineralogy, with the exception of allanite, is also characteristic of the pegmatites that cut the metamorphic rocks away from the main contact.

(3) The contact between the coarse grained porphyritic granodiorite and the metamorphic rocks is, in many cases, a complex zone of interlayered metamorphic rocks, fine grained non-porphyritic granodiorite, pegmatite, and aplite. The fine grained granodiorite may represent a chilled margin of the main body.

(4) The contacts between the granodiorite and all septa are generally sharp. If the granodiorite has developed by replacement there would probably be gradational contacts between the unreplaced remnants (septa) and granodiorite.

Diabase Dikes

Long, thin, vertical dikes of fine to medium grained diabase occur in the Kings Mountain-Henry Knob area. The thickness of the dikes is variable from about 10 to 60 feet. Some dikes can be traced along their strike for only a few thousand feet but others are continuous for several miles. They have a common northwest trend. Their emplacement seems to have been controlled to some extent by the thick bodies of kyanite quartzite. Diabase dikes never cut these thick bodies but commonly cross quartzite beds where the beds are greatly thinned, or where quartzite beds have pinched out.

Petrologically, the diabase dikes are very similar. The rock is seen in thin section to consist principally of pyroxene and labradorite with variable amounts of olivine. The texture is typically ophitic. A thin section of a one-inch diabase dike shows it to consist of strongly euhedral olivine and a few long laths of labradorite set in an extremely fine grained brownish groundmass. This convincingly shows that olivine had crystallized before the bulk of the labradorite and before any of the pyroxene.

The intrusion of diabase dikes apparently produced no noticable metamorphism. Diabase dikes have cut kyanite quartzite at Henry Knob apparently without the conversion of any kyanite to sillimanite or mullite. Inclusions of oligoclase tonalite in diabase show no signs of metamorphism.

The emplacement of diabase dikes in this area was undoubtedly part of the Triassic(?) igneous episode that affected the entire eastern part of the Appalachian Mountain system from Alabama to Newfoundland.

STRUCTURE

Major Folds

If the assumption is made that the high alumina quartzite beds and manganiferous schists are metasedimentary units that can be correlated as shown in Figure 2, their outcrop pattern suggests two large plunging folds (Plate I) in the Kings Mountain-Henry Knob area.

Primary sedimentary features, diagnostic of tops and bottoms of beds, are generally lacking in the rocks of the district. The use of structural criteria to differentiate anticlines from synclines is not applicable in this area because the rocks have probably been subjected to more than one deformation. The anticlinal and synclinal nature of the major folds has been deduced from the following facts: cross bedding in a thin bed of quartzite at Lake Montonio, on the northwest limb of fold (II, Figure 2) indicates that the top of the bed is to the southeast, and that the fold (II) is a syncline. This cross bedding is the only diagnostic primary structure in the beds of this fold. The axial plane in the southern half of this syncline dips steeply to the northwest; north of The Pinnacle, the east limb is locally overturned but in general the axial plane here is vertical or dips very steeply. The anticlinal nature of the larger fold (I) is suggested by the fact that the adjacent fold (II) to the west is probably a syncline; furthermore, the axial plane of the syncline (II) dips to the northwest, away from the axis of the large fold (I). The high alumina quartzite beds and schists along the east limb of the anticline (I) dip very steeply.

The metamorphic history also suggests that the larger fold (I) is an anticline. Some of the rocks in the center of the fold have been albitized while the high alumina quartzites on the limbs of the fold show no sign of albitization (see Metamorphism).

The distribution of manganiferous schist lends support to the major structure as indicated in Figure 2. White (1944) shows that the outcrop pattern of manganiferous schist in this district is that of a large plunging fold which coincides exactly with the major anticline (I). The nose of this fold (as defined by the manganiferous schist beds and lenses) is at Bessemer City, about 3 miles north of Crowders Mountain. The manganiferous schist along the east limb of this fold (I) can be traced south from Bessemer City to the Kings Mountain-Henry Knob area where it occurs as septa in the Yorkville granodiorite (Figure 2). The manganiferous schist along the west limb of this fold (I) can be traced south from Bessemer City to a point about three quarter miles northwest of the north end of Crowders Mountain where it apparently lies in line with the trough of the syncline (II). Manganiferous schist does not occur in the trough of the syncline (II) in the Kings Mountain-Henry Knob area but does crop out for a long distance southwest from the southwest nose of the syncline (II). This suggests that the manganiferous schist is a younger metasedimentary unit than the kyanite quartzite beds on the limbs of the syncline (II) and that manganiferous schist has been eroded from the trough of the syncline (II). The trend of the major folds in the northwest and southern parts of the Kings Mountain-Henry Knob area is about N40E. This is also the trend of the major belt of metamorphic rocks that extends southwest from this area (see Regional Geologic Setting). The development of large northeast-trending folds (Event 5, Table I) in this major belt and in the Kings Mountain-Henry Knob area probably preceded the emplacement of the Yorkville granodiorite. The evidence suggesting this is as follows:

(1) The presence of septa of manganiferous schist indicates that the granodiorite was intruded into the east limb of the anticline (I).

(2) South of Henry Knob, the trend of the axis of the anticline (I) and the foliation are parallel to the N40E-trending contact between granodiorite and metamorphic rocks. Northeast of Henry Knob, these N40E-trending features have apparently been warped into parallelism with the north-trending granodiorite contact. The emplacement of the Yorkville granodiorite was accompanied by, or preceded by, intense deformation. This deformation may have been a late stage of the deformation that produced the major folds. Whatever its age, the deformation that accompanied the emplacement of the granodiorite produced structures that have a markedly different orientation (see discussion of small folds and flow cleavage) than the orientation of the major northeast-trending folds.

Unconformity

By comparing Figure 2 with Plate I it is obvious that the high alumina quartzite beds (B and C) and associated schists are not in contact with the same rock types on the east and west limb of the anticline (I). On the west limb, bed C lies on a thick sequence of quartz-mica schist. On the east limb beds B and C are closer together than on the west limb and are separated by a thin layer of quartz-mica schist from the underlying rocks which include biotite schist, hornblende gneiss and oligoclase tonalite. The magnitude of this unconformity is not known. This unconformity corresponds, in part, to the unconformity between the Bessemer granite (Archean) and Battleground schist (Algonkian) as proposed by Keith and Sterrett (1931). However, there is no indication of an unconformity between the chloritoid schists (Battleground schist) and the overlying kyanite quartzite and conglomerate (Kings Mountain formation-Cambrian) along Kings Mountain, as proposed by Keith and Sterrett.

Second Order Features

As noted in the discussion of the kyanite quartzite, some deposits exhibit folding on a scale intermediate between the major folds and the small isoclinal folds. Repetition of beds produced by these intermediate size folds is illustrated by the multiple parallel or en echelon beds at the north end of Clubb Mountain and at Henry Knob.

Other second-order features include the large isoclinal fold at the crest of Crowders Mountain (compare Figure 2 with Plate I), the folding of kyanite quartzite and sillimanite quartzite beds north of the Will Knox property (Figure 2 and Plate I), the folding of sillimanite quartzite at the Ryan-Purcley property (Plate II), and the folding at The Pinnacle (Plate V). The axial planes of these second-order folds are very steep or vertical and are parallel to the foliation. The axes generally plunge steeply, as do the axes of the small folds.

In most of these intermediate sized folds, and especially in those involving kyanite quartzite, there has been a marked thickening of the beds at the nose of the fold, (see Kyanite Quartzite). In several cases, individual beds of quartzite merge at the nose of a fold into one thickened mass. Figure 21 indicates the attenuation of the limbs of very small folds. Such attenuation suggests there has been an actual flowage of material to the nose of the fold. Some of the second-order folds have attenuated and somewhat disjunctive limbs (see Crowders Mountain, Figure 2).

The pattern of the second-order folds at Crowders Mountain, north of the Will Knox property, and between Crowders Mountain and the Shelton property (see suggested correlation, Figure 2) indicates that they may have formed as great drag folds during the folding of the major anticline (I).

Another second-order feature is the apparent arching just northeast of Henry Knob. The folds in the quartzite at Henry Knob plunge consistently southwest; at the Ryan-Purcley property all linear structures plunge northward. Southeast of the intervening area between these two deposits, gently dipping pegmatite dikes and sills are quite common. Gently dipping structures are not common in the area as a rule. A broad local arch is thereby suggested (Figure 2).

Small Folds

Small, steeply plunging isoclinal folds are characteristic of the rocks in the Kings Mountain-Henry Knob area. These folds are particularly well developed in kyanite quartzite at the noses of the second-order folds, but also occur in schist and quartzite in the general vicinity of Kings Mountain. The wave length and amplitude of these small folds varies from about one half to twenty feet. Like the second-order folds, their axial planes are vertical or dip very steeply; the strike of the axial planes is generally parallel to the foliation. Their axes generally plunge at an angle of 45 degrees or more from the horizontal. At Henry Knob, the Shelton property, and the south end of Crowders Mountain the axes plunge consistently southward. At most places, however, as in the central part of Crowders Mountain, The Pinnacle, the southwest end of the syncline (II), there is no consistency in the direction or magnitude of plunge. In the central and north part of Crowders Mountain the axial planes of these small folds are parallel to the foliation, but the axes plunge at various angles to the north and south, many axes are vertical, and some are horizontal. The fact that the axial planes of these small folds are parallel to the flow cleavage, which is, in part a slip cleavage (see beyond), suggests that the small folds were produced by shearing along vertical or steeply dipping planes. The inconsistent orientation of these small folds with respect to the major and second-order folds suggests that the small folds developed later than the other two; there is good evidence (see flow cleavage) to indicate that the strong flow cleavage also developed later than the major folds. The development of these small folds and the flow cleavage probably occurred during the deformation that accompanied the emplacement of the Yorkville granodiorite.

Similar steeply plunging small folds have been described in many metamorphic areas (Knopf and Ingerson 1938, p. 59). Derry (1939, pp. 128-130) describes small steeply plunging folds in the pre-Cambrian rocks of Canada and concludes they developed later (and independent of) an earlier major folding. It is believed that the folds in the Kings Mountain-Henry Knob area developed in response to shearing along vertical planes. The inclination of shearing movement—probably normal to the plunge of the small fold axes—was in general less than 45 degrees from the horizontal.

Lineation

In addition to the axes of small folds, a strong lineation is defined in most of the metamorphic rocks by the parallel orientation of minerals and mineral aggregates. Kyanite blades define the strongest lineation; they are generally oriented parallel to the axes of small folds. The parallel orientation of hornblende needles within the plane of foliation commonly defines a steeply plunging lineation. Other linear elements include elongated and flattened pebbles (Figure 10), pencil-like fragments produced by the elongated fragments in the schistose pyroclastic rock (Figure 8) and crinkles (Figure 7). These last four linear elements have very gentle plunges. The crinkles, which occur on the steeply dipping flow cleavage planes in schist, are very widespread. Individual crinkles commonly have an amplitude of 1 to 2 millimeters and a wave length of 2 to 10 millimeters. The crinkles in most cases have formed from the intersection of a slip cleavage at a high angle to the flow cleavage. The development of crinkles probably occurred late in the last deformation.

Flow Cleavage (foliation)

The most common structural feature in all metamorphic rocks of the area is a strong flow cleavage defined by the parallel orientation of micas, seams of flattened aggregates of kyanite and sillimanite, and flattened pebbles. This flow cleavage invariably has a steep dip or is vertical. The strike of the flow cleavage varies from about N40E in the vicinity south of Henry Knob, to N-S in the northern part of the area. In most of the area the flow cleavage is parallel to bedding but in the northwest part of the area the flow cleavage transects bedding. A strong flow cleavage, striking from N5E to N20E, transects both limbs of the N40E-trending syncline (II, Figure 2; see also Plate I). This flow cleavage is parallel to the flow cleavage east of this syncline and also parallel to the Yorkville granodiorite contact. It is concluded that this flow cleavage developed during the emplacement of the granodiorite, at some time later than the development of the major folds.

In several places along Kings Mountain, and also at Clubb Mountain, there is good evidence of some slippage along the vertical or steeply dipping flow cleavage planes. At Kings Mountain, some of the thin kyanite-rich layers that lie stratigraphically below the kyanite quartzite, have been sharply bent and dragged a few feet horizontally along the cleavage planes which transect the bedding; small slippage along cleavage planes was also seen in a few thin sections of kyanite quartzite from this area. At Clubb Mountain a strong north-trending flow cleavage in schist has been offset along closely spaced northeast-trending slip cleavage planes (see two cleavage directions in schist between kyanite quartzite lenses, Plate VI).

Joints

Most of the highly foliated rocks exhibit vertical or steeply dipping joints at right angles to the flow cleavage.

Kyanite quartzite and conglomerate characteristically show several well developed joint planes. The most common orientation is one in which the joints are vertical or steeply dipping and perpendicular to the plane of foliation. Joints (ac) perpendicular to the axes of small steeply plunging folds are also common. Horizontal, or gently dipping joints are common at The Pinnacle. These joints are also in the ac plane with respect to the small steeply plunging folds. These horizontal or gently dipping joints are responsible for the flat gently south-sloping surface of The Pinnacle.

Evidence of Two Deformations

The following evidence suggests that the metamorphic rocks in the district have probably been subjected to two deformations:

(1) Both limbs of the N40E-trending syncline (II) are transected by a N5E to N20-trending flow cleavage.

(2) The axis of this syncline has a sinuous trace which may indicate that the initial fold has been warped. This warping probably occurred during the development of the prominent flow cleavage.

(3) The axes of the major folds in the Kings Mountain-Henry Knob area appear to have been warped from a N40E trend to a more northerly trend that is parallel to the Yorkville granodiorite contact.

(4) The small plunging folds, so profuse in kyanite quartzite, show no consistent relation to the major folds; their axial planes are parallel to the flow cleavage.

(5) The flow cleavage in schist at Clubb Mountain is offset along closely spaced slip cleavage surfaces.

To summarize: the first major deformation produced the major northeast-trending folds; the emplacement of the Yorkville granodiorite, probably late in the first period of deformation, was accompanied by intense shearing along planes parallel to the granodiorite contact; this shearing developed a strong flow cleavage (in part a slip cleavage), and profuse small plunging folds, and it also resulted in the warping of the major folds.

Emplacement of Diabase Dikes

The intrusion of diabase dikes was a much later phenomenon than any of the deformation described above. In general, the dikes were emplaced with very little structural disturbance; they have a common northwest trend. Local stratigraphic features such as the termination or thinning of thick quartzite beds seem to have played a large part in determining the emplacement of these dikes. The local occurrence of slickensided surfaces on schist near the dikes, and the fact that the flow cleavage in some schists has locally been rotated into parallelism with the dikes, suggest that some of the dikes were intruded along faults.

METAMORPHISM

A major dynamothermal metamorphism accompanied the emplacement of the Yorkville granodiorite. This premise is based on the fact that the metamorphic rank (as indicated by the distribution of metamorphic facies, and the distribution of certain minerals such as garnet and sillimanite) increases toward the granodiorite contact. The rocks in the Kings Mountain-Henry Knob area, with the exceptions of the granodiorite and diabase, indicate a degree of metamorphism ranging from the greenschist facies, or lower part of the albite-epidote amphibolite facies, to the upper part of the amphibolite facies (Turner, 1948). A minor, but widespread retrogressive metamorphism occurred after the development of the principal mineral assemblages.

Facies.

The following list indicates the principal mineral assemblages of the metamorphic rocks in the Kings Mountain-Henry Knob area and the general location of the rocks in which each mineral assemblage occurs. The metamorphic facies, corresponding to each mineral assemblage, is that given by Turner (1948). Quartz is common to all of these assemblages except in two cases which are noted below.

Mineral Assemblage	Locality	Facies
albite-chlorite	North of Stepps Gap; east of Oak View Baptist Church	greenschist
mica-chlorite	The Pinnacle and Kings Mountain	greenschist
chloritoid-chlorite-mica	The Pinnacle and Kings Mountain	greenschist or albite-epidote amphibolite

Mineral Assemblage	Locality	Facies
chloritoid-garnet-mica	The Pinnacle and Kings Mountain	albite-epidote amphibolite
Albite-epidote-hornblende	The Pinnacle and Kings Mountain	albite-epidote amphibolite
albite-epidote-biotite	Yellow Ridge	greenschist or albite-epidote amphibolite
kyanite-chloritoid	North end of Kings Mountain	albite-epidote amphibolite
tremolite-albite-epidote	Trinity Church	albite-epidote amphibolite
kyanite(quartzite)	See Plate I	greenschist, albite-epidote amphibolite and amphibolite
kyanite-staurolite	North-central part of area	amphibolite
biotite-oligoclase-garnet ± microcline	Central area north of Henry Knob	amphibolite
hornblende-andesine (or oligoclase)-epidote	Central area north of Henry Knob	amphibolite
biotite-garnet-staurolite-oligoclase	Southeast of Crowders Mountain	amphibolite
biotite-oligoclase-sillimanite	Near Yorkville granodiorite contact	amphibolite
hornblende-labradorite-epidote	Southeast of Henry Knob	amphibolite
sillimanite-muscovite	Septa and just west of granodiorite contact	amphibolite
sillimanite(quartzite)	Septa and just west of granodiorite contact	amphibolite
spessartite-hornblende	Septa	amphibolite
hornblende-andesine (no quartz)	Septa	amphibolite

Mineral Assemblage	Locality	Facies
cordierite-andesine-biotite	Septa	amphibolite
anthophyllite-andesine	Septa	amphibolite
sillimanite-corundum-microcline(no quartz)	Septa	amphibolite

There seem to be no conspicious anomalies in the distribution of the various facies in the field. In this respect it is interesting to note the local occurrence of kyanite (quartzite) in contact with chlorite-albite schist at the south end of the syncline (II, Figure 2; Plate I). Kyanite quartzite is surrounded by chloritoid-mica schist and chloritoid-garnet-mica schist in the central part of the syncline (II). Because of the presence of garnet, and the association of these schists with albite-epidote-hornblende gneiss, these chloritoid-bearing schists are thought to belong to the albite-epidote amphibolite facies; toward the south end of the syncline garnet is lacking from the schists and chlorite and albite occur locally together. Chlorite-albite schists also occur in the vicinity southeast of Stepps Gap. It appears, therefore, that schists of the albite-epidote amphibolite facies in the central part of the syncline grade into schists of the greenschist facies near the south end of the syncline. The fact that kyanite quartzite can be traced from an environment of albite-epidote amphibolite facies into greenschist facies is thought to be good evidence indicating that kyanite can develop in such low rank rocks as the greenschist facies. Inherent in this premise, however, is the fact that kyanite is thought to have been developed by the metamorphism of clay (see beyond) and not by the release of alumina resulting from the interaction of two minerals. Kyanite has also been recorded in other areas as occurring in rocks of the greenschist facies (Chapman, 1939, p. 173; Turner, 1948, p. 94). It appears that kyanite can develop over a wide range of conditions and is not necessarily a high rank metamorphic mineral as originally thought by Barrow (Chapman, 1939). True, if one restricts himself to kyanite quartzites. Probably still true in typical kyanite schists.

<u>Problem of Polymetamorphism.</u>

The following mineralogical evidence may indicate that a metamorphism occurred prior to the major dynamothermal metamorphism:

(1) Chloritoid, a characteristic mineral of the greenschist and albite-epidote amphibolite facies, occurs locally with staurolite, a characteristic mineral of the amphibolite facies; in most of these cases chloritoid appears to have altered to staurolite. Chloritoid also occurs locally as anhedral remnants in sillimanite quartzite, a rock which in this case belongs to the amphibolite facies.

(2) Andalusite shows abundant evidence of having formed earlier than some of the other metamorphic minerals; in several cases it has been partially or wholly replaced by one of the following minerals: kyanite, sillimanite, or staurolite.

(3) Kyanite has been replaced, to a small extent, by quartz. That this replacement was not a low temperature retrograde phenomenon is shown in some cases by the presence of sillimanite intimately ingrown with the quartz. Kyanite has locally been replaced by sillimanite.

Some of the replacements listed above, have also been recorded in other regions and interpreted as indicating polymorphism. (Harker, 1932, pp. 342-343). In the present instance, however, it is believed that most of this mineralogical evidence can be logically interpreted as indicating a single major metamorphism. These interpretations are as follows:

A. The relict minerals in most of the cases cited above are lower grade minerals than those that replace them. This brings up the problem of whether mineralogical evidence alone can ever be relied upon to indicate polymetamorphism in which the last metamorphism is the highest grade.

B. Much of the mineralogical evidence involves the polymorphs of $Al_2O_3 \cdot SiO_2$. It is very likely that most of the replacement textures involving these minerals resulted from steps in polymorphic transformation produced by a single metamorphism rather than two metamorphisms. Furthermore, the instances of polymorphic transformations are not generally common; i.e., the great bulk of kyanite in quartzite probably did not arise from the metamorphism of andalusite quartzite, nor did the bulk of andalusite-bearing sillimanite quartzites arise from metamorphism of kyanite quartzite. Each one of the polymorphs is thought to have developed directly from clay in the sedimentary rocks; locally, and especially near the granodiorite contact where certain conditions prevailed (see beyond) transformations occurred.

C. The staurolite-chloritoid rock may merely indicate that the conditions under which this rock developed were near the border line between the amphibolite facies and albite-epidote amphibolite facies. This boundary is admittedly vague (Turner, 1948, p.89). Regardless of what facies are involved, it seems logical that in any metamorphic area in which there is a progressive increase in rank in space, there must be some place where one mineral and its higher grade equivalent meet. The fact that chloritoid is replaced to a minor extent by staurolite may indicate a slight advance of the metamorphic zones outward from the intrusion after chloritoid had formed.

D. The local replacement of andalusite by staurolite may have resulted from the reaction: andalusite + iron oxide + water → staurolite. Although this replacement may indicate polymetamorphism, it is also possible that it merely represents two steps in the development of some staurolite. Thus, if the velocity of formation (see beyond) of andalusite from clay is faster than the formation of staurolite from clay and iron oxide, it might be expected that andalusite would form prior to staurolite; if the temperature remained sufficiently high and the necessary water was present, staurolite might form later according to the equation given above.

E. The replacement of kyanite and andalusite by quartz may be a retrograde phenomenon in many cases (see retrogressive metamorphism). Near the Yorkville granodiorite contact, however, andalusite and kyanite are locally replaced by quartz; as sillimanite is intimately intergrown with this quartz this replacement can hardly be considered a retrograde phenomenon. Andalusite and kyanite probably formed <u>locally</u> along the granodiorite contact during the initial stages of metamorphism; their structures probably broke down in response to the sustained high temperatures and hence they may have been susceptible to replacement by quartz as well as sillimanite.

Development of the High Alumina Minerals.

Andalusite.

Andalusite is believed to have developed directly by the metamorphism of clay in the sedimentary rocks. If this clay had thecomposition of kaolinite, the metamorphism can be represented thus:

$$\underbrace{Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O}_{\text{kaolinite}} \rightarrow \underbrace{Al_2O_3 \cdot SiO_2}_{\text{andalusite}} + \underbrace{SiO_2}_{\text{quartz}} + 2H_2O$$

The distribution of andalusite is puzzling, for it is a widespread accessory mineral in schists adjacent to many beds of kyanite quartzite but does not generally occur in the kyanite quartzite; however, andalusite commonly occurs as an accessory mineral in sillimanite quartzite. In both of these occurrences (schist and sillimanite quartzite) andalusite has been replaced by various minerals and there is no doubt that it developed early in the metamorphic history.

Two facts suggest that andalusite developed in response to the thermal effect of the grandiorite intrusion:

(1) Andalusite is most abundant in the high alumina quartzite beds near the granodiorite contact.

(2) Andalusite was not found in schists farther than about 2½ miles from the granodiorite contact.

There is no reason to indicate that andalusite developed as a result of <u>purely</u> thermal metamorphism; it is quite possible that it developed during the initial stages of dynamothermalmetamorphism. It occurs in rocks of the albite-epidote amphibolite facies and amphibolite facies.

The puzzling distribution of andalusite may be explained as follows: andalusite developed to a small extent as a forerunner to sillimanite yet there is no evidence of the widespread development of andalusite as a forerunnerto kyanite in the kyanite quartzite. It is concluded that kyanite (in quartzite) and andalusite (in adjacent schist) developed at about the same time. Perhaps a subtle difference in chemical composition of the parent clay, or the presence of different accessory minerals favored one polymorph over the other. It is very doubtful that physical conditions (i.e. stress or pressure) in the quartzite could have been sufficiently different from those in the adjacent schist so as to favor the development of one polymorph over the other. Although there is no direct indication, the presence of small to moderate amounts of magnetite in the andalusite-bearing schists suggeststhat the development of the andalusite structure was favored by the presence of the ferrous (or magnesium?) ion. This idea is apparently substantiated by the fact that when andalusite does occur in quartzite with kyanite, it is accompanied by the ferrous and magnesium minerals, chloritoid, staurolite,and magnetite. The iron (mainly pyrite) in most kyanite quartzite beds in the area may have been introduced after the development of kyanite (see beyond).

The fact that andalusite occurs as a forerunner to sillimanite in sillimanite quartzite, and also in schists adjacent to sillimanite quartzite, may indicate that the thermal effect near the granodiorite was stronger than the thermal effect near kyanite quartzite; this strong thermal effect may have over-balanced any subtle compositional differences and produced andalusite in both sillimanite quartzite and adjacent schist.

Kyanite.

Kyanite is believed to have developed largely through the metamorphism of clay in the sedimentary rocks and, locally near the granodiorite contact, through replacement of andalusite. The consistant linear orientation of kyanite blades with respect to the small folds and foliation leaves little doubt that kyanite formed in response to dynamothermal metamorphism. Kyanite occurs in quartzite beds and, to a minor extent, in adjacent schist. If andalusite is also present in this schist it is seen to be partially replaced by the kyanite. Kyanite developed in rocks ranging from the greenschist facies to the amphibolite facies.

Kyanite also occurs in veins with quartz that cut the kyanite quartzite. These veins were supposedly produced by metamorphic differentiation of the kyanite quartzite (see Kyanite Quartzite).

Sillimanite.

Sillimanite appears to have developed primarily by the metamorphism of clay in the high alumina sediments, and also developed by the local replacement of andalusite and kyanite. The development of sillimanite occurred during the peak of the dynamothermal metamorphism. With two minor exceptions, sillimanite was found only in rocks of the amphibolite facies.

Unlike kyanite and andalusite, sillimanite is a widespread accessory mineral in some septa and in schists and gneisses near the grandiorite contact. The occurrence of sillimanite in these rocks suggests that the alumina was derived from the replacement or breakdown of high alumina minerals such as muscovite. Two possible mechanisms for the release of alumina from muscovite are:

$$(1)\quad \underset{\text{muscovite}}{\underline{KAl_3Si_3O_{10}(OH)_2}} + \underset{\text{quartz}}{\underline{SiO_2}} \rightarrow \underset{\text{microcline}}{\underline{KAlSi_3O_8}} + \underset{\text{sillimanite}}{\underline{Al_2O_3 \cdot SiO_2}} + H_2O$$

$$(2)\quad \underset{\text{muscovite}}{\underline{KAl_3Si_3O_{10}(OH)_2}} \rightarrow \underset{\text{microcline}}{\underline{KAlSi_3O_8}} + Al_2O_3 + H_2O$$

According to Ramberg (1952, p. 48) the replacement of muscovite by quartz to yield potash feldspar, sillimanite and water (equation 1) takes place at the border between the amphibolite facies and granulite facies; Turner and Verhoogen (1950, p. 457) indicate that this reaction takes place in a high-grade sub-facies of the amphibolite facies.

The evidence indicating that this reaction (1) may have taken place in some of the rocks of the Kings Mountain district is as follows: muscovite is seen locally to be replaced by quartz; sillimanite occurs intergrown with this quartz; sillimanite occurs as needles that project into (replace?) muscovite; sillimanite is locally abundant in microcline-rich gneiss.

The derivation of alumina by the breakdown of muscovite (equation 2) is indicated by Harker (1932, p. 238) to occur in the "sillimanite zone" of metamorphism. Possibly this mechanism accounts for some sillimanite in septa or near the granodiorite contact; it is quite probable that this reaction (2) accounts for the development of corundum in the Kings Mountain-Henry Knob area.

Corundum.

Corundum occurs as euhedral crystals commonly imbedded in microcline. Sillimanite is a common associate of these minerals. Corundum is restricted to rocks that occur as septa in the granodiorite. The association of corundum with microcline strongly suggests that both formed together, and possibly through the breakdown of muscovite. In most of the thin sections of corundum-bearing gneiss, the corundum is seen to be rimmed by muscovite (Figure 31) ; in some cases corundum occurs imbedded in muscovite with no trace of microcline. It is concluded that after the development of corundum and microcline from muscovite, late hydrothermal fluids brought about a reaction between potash feldspar and corundum to form a reaction rim of muscovite about corundum.

Minor amounts of corundum occur in one sillimanite quartzite septum. The corundum here may have developed through metamorphism of a high alumina pocket of clay.

Conclusions.

The following factors appear to have played a major role in the development of andalusite, kyanite, and sillimanite: temperature, composition of parent material, and hydrothermal fluids.

Temperature.

The overall distribution of sillimanite quartzite and kyanite quartzite (Plates I and II) with respect to the Yorkville granodiorite contact suggests that higher temperatures favored the development of sillimanite over kyanite. An even more striking distribution of kyanite and sillimanite is shown by the two long parallel beds north of the Will Knox property (Plate I). These beds can be traced for about 4000 feet along their strike. The eastern-most bed lies from 80 to 1200 feet from the Yorkville granodiorite contact. It consists of sillimanite quartzite with andalusite. The westernmost bed lies from 1200 to 3000 feet from the granodiorite contact. It consists of kyanite quartzite except in the middle part, over a distance of 1000 feet, where it is sillimanite quartzite. The sillimanite portion of this bed lies closer to the granodiorite contact than either the north or south portions where the bed consists of kyanite quartzite.

The distribution of andalusite also suggests that the thermal energy from the intrusion played a major part in the development of andalusite.

In the cases where two or more of the polymorphic forms occur together the paragenetic sequence is seen to be: andalusite replaced by kyanite or sillimanite; kyanite replaced by sillimanite; sillimanite replaced by neither of the other (see Sillimanite Quartzite). It is interesting that these replacements were noted principally in quartzite near the granodiorite. This may indicate that these transformations were produced largely by an increase in thermal energy; it is also possible that fluids given off by the intrusion acted as a catalyst in bringing about these transformations. These transformations agree in part with the theoretical sequence of polymorphic transformations suggested by Turner and Verhoogen (1951, pp. 379,386,412). They suggest that sillimanite is the stable form of $Al_2O_3 \cdot SiO_2$ over a wide temperature range and that andalusite (a metastable form) commonly develops before sillimanite because of the higher velocity of the andalusite formation; kyanite is thought to develop more readily from andalusite than does sillimanite because the transformation andalusite → kyanite requires a smaller structural change than does the transformation andalusite → sillimanite. ← not so! give evidence.

The common association of andalusite and sillimanite near the Yorkville granodiorite contact, and the fact that sillimanite has replaced andalusite without the intermediate development of kyanite is in contradiction to the theoretical view that kyanite should form more readily from andalusite than should sillimanite. The answer to this problem may be found in the catalytic effect of fluids supplied by the intrusion. Perhaps..

all of the Al_2SiO_5 polymorphs are unstable in presence of abundant water above 550°C — ([illegible], 1950) this water aided in bringing about the most structurally difficult transformation (andalusite → sillimanite).

Composition of parent material.

The composition of the parent clay from which the three polymorphs developed, is thought to have been important in determining whether andalusite or kyanite developed. Furthermore, the crystalline structure of the clay may have been important, for the $Al_2O_3 \cdot SiO_2$ polymorph would form whose structure was most closely akin to that of the clay.

Hydrothermal fluids.

The role of hydrothermal fluids is discussed in connection with the origin of the high alumina deposits. As far as the mutual relations between $Al_2O_3 \cdot SiO_2$ polymorphs are concerned, it is evident that there is no consistent paragenetic sequence between polymorphs deposited by hydrothermal fluids. Thus, unaltered sillimanite occurs in the hydrothermally altered kyanite quartzite at Clubb Mountain. Andalusite is abundant in the kyanite quartzite that has been altered to dickite at Crowders Mountain; andalusite and kyanite occur side by side in some of the rock at Clubb Mountain with no indication that one has replaced the other. These inconsistencies may be interpreted to indicate that small amounts of various ions (in addition to Al^{+3}, Si^{+4}, O^{-2}) have entered into the structure of the polymorphs and hence brought about their development under various temperature conditions.

In this connection it is interesting to note that very small amounts of kyanite and sillimanite were found locally in the granodiorite.

Retrogressive Metamorphism.

A minor but widespread retrogressive metamorphism of all the rocks in the Kings Mountain-Henry Knob area is indicated by the following structural and mineralogical evidence:

1. Garnet, chloritoid, biotite, and hornblende have been replaced to a small extent by chlorite.
2. Andalusite has been replaced by quartz, mica, and tourmaline.
3. Kyanite blades have locally been bent, fractured and pulled apart; the fractures and irregular ruptures have been filled with quartz. Kyanite has been locally replaced by quartz at Henry Knob and Clubb Mountain. The development of quartz veins and quartz-kyanite veins probably occurred during this retrogressive metamorphism.
4. Kyanite, sillimanite and diaspore have locally been altered along their crystal boundaries to clay. Another alteration that probably occurred at this time, but cannot be considered minor, is the replacement of kyanite quartzite at Clubb Mountain and Crowders Mountain by dickite. The hydrothermal stage of mineralization at Clubb Mountain resulted in the formation of several other minerals in addition to clay (see Table IX).

Metasomatism and Hydrothermal Mineralization

Metasomatism Produced by the Yorkville Granodiorite.

In that the hydrothermal stage of retrogressive metamorphism was largely influenced by the late magmatic activity of the Yorkville granodiorite, the changes brought about at this time can be considered as metasomatic products of the granodiorite.

Some of the principal materials probably introduced at this hydrothermal stage are listed below with their metasomatic products.

(a) Silica: clay alteration at Crowders and Clubb Mountains; quartz replacing some andalusite and kyanite.

any evidence that bulk mineral composition changed? probably water alone added.

(b) H_2O, P_2O_5, B, F, Cl: Clubb Mountain sequence of minerals (see Origin of High Alumina Rocks); hamlinite in clay alteration at Crowders Mountain.

OK

(c) Pyrite: The widespread development of pyrite in schists and quartzites of the Kings Mountain-Henry Knob area probably occurred during this time. Pyrite is present in the dickite alteration at Crowders Mountain. Pyrite is abundant in the kyanite quartzite at Henry Knob and the Pinnacle.

OK

(d) Barite: Barite mineralization may be related to this hydrothermal stage. Barite has been mined at two localities about one-half to one mile southeast of Crowders Mountain (See Plate I). Barite occurs principally as lenses parallel to the foliation in quartz-mica schist, and also as thin veins and seams cutting schist and kyanite quartzite. (Some barite in the area may not be of hydrothermal origin; see Origin of High Alumina Rocks.)

OK

Local potash metasomatism is nicely displayed in the biotite gneiss and schist in the immediate vicinity of barite mineralization. Veins of adularia, pervasive alteraion of plagioclase to potash feldspar, and incipient replacement of plagioclase phenocrysts by microcline are all well shown in thin section.

In general there is evidence of only slight metasomatism produced by the Yorkville granodiorite prior to the distinctly hydrothermal stage. These earlier metasomatic products include:

1. muscovite porphyroblasts in sillimanite quartzite septa.
2. the local occurrence in the septa of interstitial myrmekite, sodic oligoclase, and quartz (a characteristic intersititel aggregate of the granodiorite).

Albitization.

Local albitization of oligoclase tonalite and rocks that are now biotite gneiss and hornblende gneiss probably occurred early in the geologic history of the region. The albitizing fluids probably arose from the magma of the oligoclase tonalite (see Oligoclase tonalite, Biotite schist and gneiss, Hornblende gneiss). That this albitization is not related to metasomatism produced by the Yorkville granodiorite, is suggested by the fact that the high alumina quartzites show no sign of alkali metasomatism. As rocks with excess alumina should be highly susceptible to alkali metasomatism (Turner, 1948, p. 115) it is assumed that albitization occurred prior to the deposition of the high alumina rocks.

Gold Mineralization.

Very little information on the nature and age of gold mineralization was gathered during the present study. A few old prospects for gold were visited; these prospects occur in biotite gneiss and schist, and quartz-mica schist in the area between Crowders Mountain and Henry Knob (Plate I). Pyrite is the abundant sulphide mineral on the dumps of the prospects; no high alumina minerals were seen on the dumps. There appears to be no relation between the distribution of these prospects and the distribution of the high alumina quartzite deposits. Pardee and Parks (1948, p. 49) conclude that gold mineralization in this area was related to a late Carboniferous or early Triassic epoch of gold mineralization that affected rocks from Alabama to Virginia.

ORIGIN OF HIGH ALUMINA ROCKS

Evidence for Sedimentary Origin.

Field and petrographic evidence indicates that kyanite quartzite and kyanite conglomerate, kyanite-chloritoid-(with or without staurolite) quartzite, and sillimanite quartzite in the Kings Mountain district are metamorphosed high alumina sediments, probably sandy or silty clays. The evidence supporting this view is as follows.

A. High alumina quartzites have the distribution pattern and layered nature of stratigraphic units:

(1) Single beds (10 to 40 feet thick) of kyanite conglomerate and kyanite quartzite can be traced almost continuously along strike for distances up to three and one-half miles along Kings Mountain, and for lesser distances at other deposits. These beds are locally gradational along strike from kyanite conglomerate to kyanite quartzite to kyanite schist. The kyanite quartzites are in sharp contact with the schists immediately stratigraphically above and below which may or may not contain minor to moderate amounts of kyanite.

(2) The kyanite quartzite and conglomerate in the southern half of the syncline (II, Figure 2) occur as two parallel beds separated by about 20 to 100 feet of schists and schistose conglomerate. These paired beds can be traced for distances up to one mile on both limbs of the syncline.

100% kaolin = 65% kyanite ?

(3) Thin layers (2 to 5 feet thick), rich in kyanite (30 to 90 per cent) occur in contact with, and stratigraphically below the kyanite quartzite along the Kings Mountain ridge. These layers can be traced for distances up to 100 feet along strike. These thin beds may have been thin beds or lenses of clay.

(4) Sillimanite quartzite also occurs as well defined beds, which are generally of a more lenticular nature than the kyanite quartzite. A thin bed of sillimanite quartzite can be traced almost continuously for one-half mile along strike in the area just north of the Will Knox property. Sillimanite quartzite is generally in sharp contact with adjacent schists and non-sillimanitic quartzite.

(5) At Crowders Mountain, beds of kyanite quartzite, non-kyanite magnetiferous quartzite, and staurolite quartzite are interlayered. The contact between kyanite quartzite and either of the other quartzites is generally sharp. Chloritoid (with or without staurolite) quartzite is interlayered with kyanite quartzite south of Crowders Mountain Village.

(6) A distinct banding is defined in the kyanite quartzite at Crowders Mountain (Figure 17) by very thin (one-half to one centimeter) layers rich in kyanite and quartz alternating with layers containing quartz but no kyanite, and others containing kyanite, quartz, and mica. Such very thin layering defined by compositional differences suggests relict sedimentary bedding.

(7) Thin layering is also seen locally in some thin sections of kyanite-staurolite quartzite. The layers are from 3 millimeters to about 1 centimeter wide and are alternately rich in staurolite, quartz-chloritoid-staurolite, and chloritoid-kyanite.

(8) Some of the kyanite quartzite at Clubb Mountain exhibits local compositional banding. One thin section of kyanite quartzite and schist shows the following succession of layers: coarse grained kyanite with inequigranular quartz and very fine grained aggregates of mica; fine grained quartz and mica and fine grained random anhedral kyanite; very fine grained quartz, fine grained mica(schist) with anhedral topaz(?).

what high alumina mean? is 17% -20% alumina high?
This is normal in acidic volcanics.

B. High alumina quartzite beds occur in a sequence of high alumina metasedimentary rocks. The high alumina nature of the sequence of quartz-mica schists that surrounds the kyanite and sillimanite quartzite beds is indicated by the abundance of mica and the presence of one or more of the following accessory minerals: andalusite, kyanite, sillimanite, staurolite, chloritoid. The association of quartzites with these schists suggests that the deposition of quartzite was only one stage in the deposition of a thick sequence of high alumina sediments.

No Evidence for Hydrothermal Origin.

Newcombe (1948) and Smith and Newcombe (1951, p. 763) conclude that kyanite at Henry Knob was formed from alumina introduced by hydrothermal solutions. The evidence that Smith and Newcombe cite in favor of hydrothermal origin is listed and discussed below.

1. "Quartz-kyanite veins cutting the kyanite quartzite".

As indicated by the authors, these veins were reported by workmen and were not seen by Smith or Newcombe. The present study revealed no veins of kyanite in the quartzite at Henry Knob; some coarse grained clots and aggregates of kyanite commonly occur at the axes of small folds and these aggregates probably formed by metamorphic differentiation. In this connection it is significant that kyanite-bearing quartz veins do occur in other kyanite quartzite deposits of the district; but the fact that kyanite-bearing quartz veins were found only in kyanite quartzite suggests that the veins were formed by metamorphic differentiation. (See Kyanite Quartzite.) Quartz veins are rather common in some of the schists of the district but kyanite does not occur in any of these veins.

2. "Occurrence of seams of kyanite along contacts of schist and quartzite".

Smith and Newcombe suggest that permeability was higher along these contacts than in the quartzite, hence seams of kyanite formed at the contacts. Although coarse grained kyanite does occur at these contacts, no well defined seams of kyanite were seen at the contacts during the present study; kyanite is evenly distributed along irregular seams and foliation planes in the quartzite. The seams appear to be discontinuous offshoots from the foliation planes.

3. "Euhedral kyanite lining vugs in the quartzite".

A few small cavities were seen in kyanite quartzite during the present study. Kyanite does not appear to line these cavities but a few kyanite blades do project from the groundmass of the quartzite into these cavities. The present study also reveals that these cavities are partly filled with barite. The cavities have apparently resulted from the partial weathering out of barite (or celestite?); thus the cavities are probably not vugs in the sense that they were pockets in the rock during recrystallization. Barite may have been introduced in the final stages of metamorphism; there is also a possibility that some of it is indigenous to the parent sediment (see nature of high alumina sediments). The euhedralism of the kyanite in contact with barite may indicate that kyanite grew more freely in contact with barite than in the quartz groundmass. If this barite was of hydrothermal origin, it follows that some kyanite was still developing during the late hydrothermal stages of metamorphism (cf. Clubb Mountain sequence, beyond).

4. "Smaller crystals of kyanite in the finer grained host rock".

Smith and Newcombe suggest that permeability in the fine grained portions of the quartzite was lower than in the coarse grained portions; hence, smaller crystals of kyanite developed in the finer grained host rock. The present study revealed no such grain size relationship; in fact, coarse crystals of kyanite commonly occur in very fine grained quartzite.

5. "The association of pyrite with kyanite".

This is seemingly a valid argument for the hydrothermal origin of alumina, but the following features suggest that kyanite and much of the pyrite may not be genetically related:

(a) pyrite is abundant in the rocks of the Kings Mountain-Henry Knob area; pyrite occurs in every rock type(including the granodiorite) except diabase.

(b) The overall distribution of pyrite is somewhat sporadic as it is very abundant in kyanite quartzite at Henry Knob yet is totally lacking in some of the sillimanite quartzite.

(c) Evidence from thin section study suggests that pyrite developed later than kyanite (see Kyanite Quartzite).

It is concluded that pyrite is a product of widespread hydrothermal action; the distribution of pyrite lends no support to the hydrothermal origin of alumina. There is also a possibility that some pyrite is indigenous to the parent sediment (see beyond).

6. The highly poecilobastic texture of kyanite at Henry Knob is interpreted by Smith and Newcombe to indicate that kyanite replaced quartz. The texture may also be interpreted to indicate that quartz has replaced

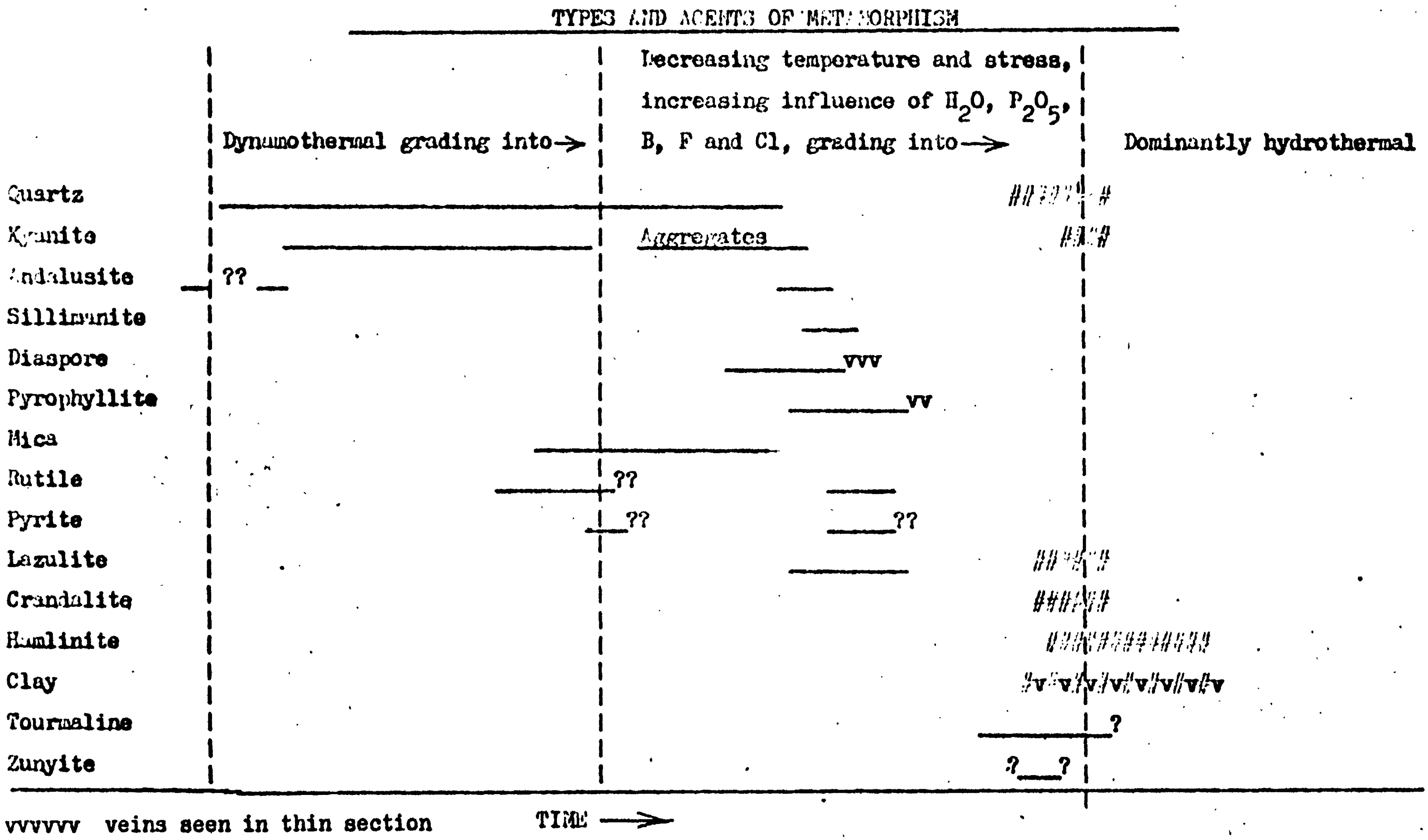
kyanite (see Kyanite Quartzite); or that the quartz inclusions represent the silica released in the metamorphism of clay to kyanite.

Smith and Newcombe (1951) suggest that the source of alumina was from the magma of the Yorkville granodiorite. In a general discussion of the origin of kyanite Stuckey (1935) concludes that emanations from pegmatites are the principal source of alumina. The present study shows that there is no space relation between the Yorkville granodiorite (or its pegmatites) and the high alumina quartzites. Kyanite quartzite occurs as close as 1200 feet and as far as four miles from the granodiorite contact.

Pegmatite dikes occur within a few tens of feet of some of the sillimanite quartzite beds, but they were never seen to be cutting the quartzite. Pegmatite dikes cut the hornblende gneiss 3000 feet east of Henry Knob, but these dikes may be related to the oligoclase tonalite, a rock distinctly older than the metasedimentary sequence of which kyanite quartzite is a member. No pegmatite dikes were found in the general vicinity of The Pinnacle, Kings Mountain, Crowders Mountain, or the Shelton Property. Although very minor amounts (2 or 3 crystals in one pan of weathered rock) of kyanite and sillimanite occur in the granodiorite at one locality, a detailed petrographic study of the granodiorite and related pegmatites indicates these rocks to be virtually free of kyanite, andalusite, and sillimanite. The local occurrence of kyanite and sillimanite in the granodiorite is believed to indicate local assimilation of the alumina from nearby septa of sillimanite schist.

TABLE IX

Summary of metamorphism and mineralogical sequence at Clubb Mountain, Lincoln County, North Carolina. The horizontal lines represent periods of recrystallization and/or crystallization.



vvvvvv veins seen in thin section

veins seen in field

To summarize: There is no direct evidence to indicate a hydrothermal origin for the alumina at Henry Knob or any other high alumina deposit in the Kings Mountain district. The evidence also indicates that the magma of the Yorkville granodiorite was probably a very unlikely source of alumina for the high alumina quartzites.

Role of Hydrothermal Fluids in Metamorphism of the High Alumina Rocks.

The presence of segregated aggregates of kyanite, and veins of hydrous alumina minerals in the kyanite quartzite at Clubb Mountain indicate that hydrothermal fluids have played an important part in metamorphism here (Table IX). Yet the kyanite is confined to long lenses and beds of quartzite that can be traced almost continuously for one and one-half miles along strike. Kyanite is disseminated in the schists immediately adjacent to the quartzite, but kyanite veins, pegmatites or other possible feeders were not found in the rocks adjacent to the quartzite. It is suggested that the hydrothermal fluids (OH, P_2O_5, B, F, and Cl) brought about an internal mobilization of alumina indigenous to the quartzite. This hydrothermal activity is believed to have occurred in the late stages of dynamothermal metamorphism; there may have been a complete gradation from dynamothermal metamorphism to late stage hydrothermal action.

The concept of hydrothermal mobilization of alumina indigenous to a sedimentary rock is also set forth by Lemmon (1937) to explain some of the features of the andalusite deposit in the Northern Inyo Range of California (see beyond).

In other parts of the Kings Mountain district the late hydrothermal stage is also represented by clay alteration (the Shelton property and Crowders Mountain). The presence of small amounts of hamlinite and pyrite in this clay (dickite) indicates that P_2O_5 and S were introduced here as well as at Clubb Mountain.

Nature of High Alumina Sediments.

It is important to note that the kyanite and sillimanite quartzites are thin beds in a thick (several hundreds of feet) sequence of high alumina fine grained clastic rocks.

The overall outcrop pattern of the high alumina sequence of rocks suggests the presence of an unconformity between them and the underlying volcanic rocks. If such is the case, and the high alumina sediments were derived from a local source, they probably were derived in large part from this older volcanic complex.

It is assumed that the alumina for all the high alumina quartzites was deposited in the form of clay. The paucity of alkalies or alkaline earths in the high alumina quartzites indicates that this clay was probably kaolin.

It is significant that the high alumina sequence of sedimentary rocks is associated with ferruginous and manganiferous sediments. Although neither the iron or manganese-bearing sediments were studied in any detail, it is quite certain from their distribution that their origin was related to the origin of the high alumina sediments. The association of manganiferous sediments and ferruginous sediments is well known (Bateman, 1947, p. 162); furthermore, manganiferous deposits are commonly associated with rocks of the spilite and quartz keratophyre group (Turner and Verhoogen, 1951, p. 203; Park, 1946). Although the volcanic complex in the Kings Mountain-Henry Knob area includes no metavolcanic rocks that can be rigidly classified as spilites, there are definite indications that albitization associated with early igneous activity produced rocks with the composition of quartz keratophyres (see Hornblende gneiss). It is suggested that hydrothermal activity associated with the volcanic episode may have provided iron and manganese to the body of water that deposited the ferruginous and manganiferous sediments.

The development of clay is thought to have resulted principally from the chemical weathering of the volcanic complex; certain features such as the fine grained texture of the pyroclastic rocks and the inherent instability of glass and aphanitic material would have greatly promoted chemical weathering. There is also a possibility that much of the clay was actually produced by the hydrothermal alteration of the volcanic complex at shallow depths. Burbank (1950) has shown that hydrothermal alteration of volcanic complexes at shallow depths has produced large amounts of clay (dickite) and silica; pyrite and rutile are common accessory minerals in the altered rock (herein may lie the explanation for some of the pyrite and rutile in the high alumina quartzites); also the abundance of fine grained quartz and quartzite pebbles in the high alumina rocks suggests that the source rock may have been silicifed.

There are few clues to the environment of deposition of the clay, iron, and manganese sediments. The great lateral extent of manganiferous sediments occurring apparently in one position in the stratigraphic sequence, (see Regional Setting) suggests a marine environment of deposition. The ferruginous sediments may have been largely of the nature of jasper; the separate beds of manganiferous sediments and ferruginous sediments in the Kings Mountain district may reflect the well known tendency of manganese and iron to precipitate separately (Bateman, 1947, p. 162).

The chemical composition of the richest high alumina quartzites suggests that they could have formed from a mixture of about 50 per cent kaolin and 50 per cent quartz. The majority of the high alumina quartzites probably formed from sands containing less than 30 per cent kaolin. The composition of the kyanite and sillimanite quartzites is very similar to sandy clays associated with deposits of refractory clay (Greaves-Walker, 1939, pp. 43,50,66). The association of non-kyanitic quartzites with high alumina quartzites suggests an original sequence of sands and clay-rich sands such as is characteristic of parts of the Wilcox formation of Eocene age (Funnel, 1950, p.267). The sequence of high alumina meta-sedimentary rocks in the Kings Mountain-Henry Knob area differs from the Wilcox formation in that the former is intimately associated with water-lain pyroclastic rocks and contains no associated lignitic (or graphitic) beds. The association of high alumina (now kyanite quartzite), manganiferous, and ferruginous rocks with volcanic rocks also occurs in the Singhbhum province of India (Dunn, 1929,1935). Dunn concludes that the alumina was derived from the weathering or hydrothermal alteration of volcanic rocks (see beyond).

The following accessory minerals in the high alumina quartzites in the Kings Mountain district have also been reported (Mead, 1915; Allen, 1950) in clay or bauxite deposits: rutile, pyrite, barite, and zircon. As noted earlier, much of the pyrite and barite in the Kings Mountain district appear to be products of hydrothermal activity. It is difficult to assess the amount of barite and pyrite that might have been indigenous to the sediments from barite and pyrite of hydrothermal origin.

Short Summary of Other High Alumina Deposits.

A survey of the literature of the principal deposits of andalusite, kyanite, and sillimanite in the world indicates that some deposits are probably of metasedimentary origin, while others are of metasomatic origin. A brief survey of some of these deposits and the evidence used in deducing their origin follows.

Metasedimentary:

Virginia. The deposits of kyanite quartzite at Willis Mountain and Baker Mountain, Virginia, have been studied along with those of the Kings Mountain district as part of this U.S. Geological Survey project. The bedded nature of the kyanite quartzite which is interlayered with metamorphic schists and gneisses indicates a metasedimentary origin for these Virginia deposits (Espenshade and Potter, 1953). It is interesting to note that there are no large bodies of granite nearby the kyanite quartzites of Virginia. The accessory minerals of these kyanite quartzites are very similar to those found in the kyanite quartzite in the Kings Mountain district.

India. The largest deposits of high grade kyanite in the world are probably in India. Dunn (1929) indicates that in one of the major localities (Singhbhum) a belt of high alumina quartzites and schists can be traced discontinuously for about 50 miles. Kyanite occurs as lenses and pods associated with metavolcanic and metasedimentary rocks. Some of the high grade kyanite is very fine grained and occurs as massive intergrowths with corundum. Rutile is a common accessory. Dunn suggests that the kyanite and other high alumina rocks are metamorphosed residual impure bauxites, or clays derived from hydrothermal alteration of the volcanic rocks. Chatterjee (1931) proposes that the alumina for the kyanite was derived by the pneumatolytic action of boron in the reaction:

Chlorite + muscovite → biotite + andalusite.

He maintains that, in the presence of sufficient boron, tourmaline will form in lieu of biotite. Such a theory may be valid for reaction of a local nature but the amount of tourmaline that would have to form in order to produce the lenses and pods of kyanite is more than the recorded field evidence suggests.

California. The large andalusite deposit in the White Mountains of California has been studied by Jeffrey and Woodhouse (1931), Kerr (1932) and Lemmon (1937). They agree that this deposit is probably a metamorphosed high-alumina sediment (now a quartzite); Kerr and Lemmon stress the point that hydrothermal action has been important in the metamorphism of this deposit. Lemmon suggests that much mobilization of aluminous material has occurred, as andalusite occurs in shear and fault zones in metaquartzite.

Most of the high alumina minerals here also occur in the high alumina quartzites of the Kings Mountain district.

Metasomatic.

Australia. One of the best documented descriptions of high alumina deposits formed by replacement is that by Alderman (1942,1948, 1950) on the deposits near Williamstown, South Australia. The deposit consists of large bodies of kyanite-sillimanite rock that are seen in the field to cut across the regional grain of the country rock. The country rock consists of a series of low grade schists, marbles, and quartzites invaded by pegmatites. The sequence of replacement (generalized from

Alderman) is: massive kyanite-quartz → massive sillimanite-quartz → massive kyanite-quartz → kyanite-quartz veins → kyanite pegmatite → pegmatite → clay-muscovite. The sequence, he believes, records first a rise and then a general decline in temperature and alumina concentration in solution.

Southeastern United States. Many high alumina quartzite deposits in the Piedmont of southeastern United States have field relations suggesting that they are replacement deposits (Espendhade and Potter, 1953). The structure of these deposits generally bears little relation to the regional structure. The deposits are criss-crossed with quartz and pyrophyllite veins. Lazulite is a common accessory mineral. These deposits show no well developed planar structures such as foliation or bedding. Kyanite occurs as random massive aggregates with the quartzite. Examples of this type are Graves Mountain, Georgia; a deposit at Smithfield, North Carolina; Hagers Mountain, North Carolina.

Conclusions.

There appears to be good evidence that some high alumina quartzite deposits are of metasedimentary origin; others appear definitely to be of metasomatic origin. There may well be a gradation between metasedimentary deposits like Clubb Mountain, where hydrothermal action has probably mobilized indigenous alumina, and the White Mountain andalusite deposit, where the alumina from a sedimentary rock has been redistributed into shears and fractures. The association of many high alumina quartzite deposits of metasomatic origin with volcanic rocks suggests that the alumina and quartz were derived from the volcanic rocks. In some cases, these metasomatic high alumina quartzite deposits may represent a single stage of hydrothermal alteration; in other cases the deposits may represent mobilized alumina and silica that were previously derived by weathering of the volcanic complex, or by hydrothermal activity that attended the late stages of a volcanic episode.

REFERENCES CITED

Alderman, A.R., 1942, Sillimanite, kyanite and clay deposits near Williamstown, S. Australia, Trans. Roy. Soc. S. Australia, vol. 66, pp. 3-14.

________ 1948, The genesis of Sillimanite and Kyanite Rocks by Alumina Metasomatism, 18th Int. Geol. Congress, Part II, Metasomatic Processes in Metamorphism, pp. 125-126.

________ 1950, Clay derived from sillimanite by hydrothermal alteration, Min. Mag., vol. 29, no. 211, pp. 271-279.

Allen, V.T., 1950, Petrography of the Wilcox Formation of Arkansas, (Abstract) Geol. Soc. America, Bull., vol. 61, pp. 1440-1441.

Bateman, A.M., 1947, Economic Mineral Deposits, John Wiley and Sons, Inc., New York, 898 pages.

Broadhurst, S.D., and Councill, R.J., 1953, A preliminary report on high alumina minerals in the volcanic-slate series, North Carolina, N. Carolina Dept. Conserv. Dev., Div. Min. Resources, Inf. Circ. 10, 22 pages.

Burbank, W.S., 1950, Problems of Wall-Rock Alteration in Shallow Volcanic Environments, Quart. Colo. School Mines, vol. 45, no. 1b, pp. 287-319.

Chapman, C.A., 1939, Geology of the Mascoma Quadrangle, New Hampshire, Geol. Soc. America Bull., vol. 50, pp. 127-180.

________ 1950, Quartz veins formed by metamorphic differentiation of aluminous schists, Am. Min., vol. 35, pp. 693-710.

Chatterjee, S.K., 1931, On certain rocks bearing kyanite and sillimanite in the Bhandara District, India Geol. Survey, Records, vol. 65, part 2, pp. 285-305.

Derry, D.R., 1939, Some Examples of Detailed Structure in Early Pre-Cambrian Rocks of Canada, Quart. Journ. Geol. Soc. London, vol. 95, pp. 109-134.

Dunn, J.A., 1929, The Aluminous Refractory Materials: Kyanite, Sillimanite and Corundum in Northern India, Mem. Geol. Survey India, vol. 52, part 2, pp. 145-274.

________ 1935, The Origin of Iron Ores in Singhbhum, India, Ec. Geol., vol. 30, pp. 643-654.

Eardley, A.J., 1951, Structural Geology of North America, Harper and Brothers, New York, 624 pages.

REFERENCES CITED (cont.)

Espenshade, G.H., and Potter, D.B., 1953, Kyanite Quartzite Deposits of the Southeastern States (Abstract), Geol. Soc. America Bull., vol. 64, no. 12, part 2, p. 1530.

Funnell, J.E., 1950, Wilcox Group Clays in Arkansas, Am. Ceramic Soc. Bull. vol. 29, no. 8, pp. 286-289.

Genth, F.A., and Kerr, W.C., 1881, The Minerals and Mineral Localities of North Carolina, Geology of North Carolina, Ch. I, vol. 2, Raleigh, pp. 1-122.

Gilluly, James, 1935, Keratophyres of Eastern Oregon and the Spilite Problem, Am. Journ. Sci., Fifth Series, vol. 29, no. 171, pp. 225-252.

Greaves-Walker, A.F., 1939, The Origin, Mineralogy and Distribution of the Refractory Clays of the United States, N. Carolina State College of Agric. and Eng., State College Record, vol. 39, no. 4, 87 pages.

Griffitts, W.R., and Olsen, J.C., 1953, Mica Deposits of the Southeastern Piedmont, Part 5. Shelby-Hickory District, North Carolina, U.S. Geol. Survey Prof. Paper 248-D, pp. 203-281.

Harker, Alfred, 1932, Metamorphism, Methuen and Co., Ltd., London, 362 pages.

Hash, L.J., and Van Horn, E.C., 1951, Sillimanite Deposits in North Carolina, N. Carolina Dept. Conserv. and Dev., Div. Min. Resources Bull. no. 61, 51 pages.

Hietanen, Anna, 1951, Metamorphic and Igneous Rocks of the Merrimac Area, Plumas National Forest, California, Geol. Soc. America Bull., vol. 62, pp. 565-608.

Hunter, C.E., and White, W.A., 1946, Occurrences of Sillimanite in North Carolina Dept. Conserv. and Dev., Div. Min. Resources, Inf. Circ. 4.

Jeffrey, J.A., and Woodhouse, C.D., 1931, A note on a deposit of Andalusite in Mono County, California; its occurrence and technical importance, Report 27 of State Mineralogist, pp. 459-464.

Johannsen, Albert, 1932, A Descriptive Petrography of Igneous Rocks, University of Chicago Press, Chicago.

Keith, Arthur, and Sterrett, D.B., 1931, Jaffney-Kings Mountain, S. Carolina-N. Carolina, U.S. Geol. Survey Atlas, Folio no. 222.

Kerr, P.F., 1932, The occurrence of Andalusite at White Mountain, California, Ec. Geol., vol. 27, no. 7, pp. 614-644.

REFERENCES CITED (cont.)

Kerr, W.C., 1875, Report of the Geological Survey of North Carolina, Raleigh, pp. 1-120.

King, P.B., 1951, Tectonics of Middle North America, Princeton Univ. Press, Princeton, 203 pages.

Knopf, E.B., and Ingerson, Earl, 1938, Structural Petrology, Geol. Soc. America Mem. 6, 270 pages.

Laney, F.B., 1910, The Gold Hill District, N. Carolina Geol. Survey, Bull. 21, pp. 1-137.

________ 1917, The Geology and Ore Deposits of the Virgilina District of Virginia and North Carolina, N. Carolina Geol. Survey Bull. 26.

Lemmon, D.M., 1937, Geology of the Andalusite Deposits in the Northern Inyo Range, California, (Doctorate Dissertation), Stanford University.

Mead, W.J., 1915, Bauxite Deposits of Arkansas, Ec. Geol., vol. 10, pp. 28-54.

Newcombe, R.C., 1949, Kyanite at Henry Knob, South Carolina, Master of Science Thesis, University of South Carolina.

Nitze, H.B.C., 1893, Iron Ores of North Carolina, N. Carolina Geol. Survey Bull., no. 1, 239 pages.

Pardee, J.T., and Park, C.F., 1948, Gold Deposits of the Southeastern Piedmont, U.S. Geol. Survey Prof. Paper 213, pp. 1-156.

Park, C. F., 1946, The spilite and manganese problem of the Olympic Peninsula, Washington, Am. Jour. Sci., vol. 244, pp. 305-323.

Pogue, J.E., 1910, The Cid Mining District of Davidson County, No. Carolina Geol. Survey Bull. 22, pp. 1-140.

Ramberg, Hans, 1952, The Origin of Metamorphic and Metasomatic Rocks, Univ. Chicago Press, Chicago, 317 pages.

Read, H.H., 1934, On quartz-kyanite rocks in Unst, Shetland Islands, and their bearing on metamorphic differentiation, Min. Mag., vol. 23, pp. 316-328.

Sloan, Earle, 1908, Catalogue of the mineral localities of South Carolina, S. Carolina Geol. Survey, Series, IV, Bull. 2, pp. 1-505.

REFERENCES CITED (cont.)

Smith, L.L., and Newcombe, Roy, 1951, Geology of Kyanite Deposits at Henry Knob, South Carolina, Ec. Geol., vol. 46, no. 7, pp. 757-764.

Spencer, Edmonson, 1945, Myrmekite in graphic granite and in vein perthite, Min. Mag., vol. 27, no. 189, pp. 79-98.

Stuckey, J.L., 1928, The Pyrophyllite Deposits of North Carolina, N. Carolina Dept. Conserv. and Dev., Div. Min. Resources Bull. 37, p. 1-62.

_______ 1935, Origin of Cyanite (A Discussion), Ec. Geol., vol. 30, pp. 444-450.

Turner, F.J., 1938, Mineralogical and Structural Evolution of the Metamorphic Rocks, Geol. Soc. American Mem. 30, 343 pages.

_______ and Verhoogen, Jean, 1951, Igneous and Metamorphic Petrology, McGraw-Hill, New York, 602 pages.

Van Horn, E.C., Le Grand, J.R., and McMurray, 1949, Geology and Preliminary Ore Dressing Studies of the Carolina Barite Belt, Res. Plan. and Dev. Board, State of S. Carolina, Bull. no. 18, pp. 1-25.

Washington, H.S., 1917, Chemical Analyses of Igneous Rocks, U.S. Geol. Survey Prof. Paper 99, pp. 1-1201.

Watson, T.L., 1909, Petrology of the South Carolina granites, Journ. Geol., vol. 17, pp. 730-751.

_______ 1910, Granites of southeastern Atlantic States, U.S. Geol. Survey Bull., 426, pp. 1-282.

Wells, R.C., 1937, Analyses of rocks and minerals from the laboratory of the U.S. Geological Survey, 1914-36, U.S. Geol. Survey Bull. 878, pp. 1-134.

White, W.A., 1944, Manganese Deposits in North Carolina, N. Carolina Dept. Conserv. and Dev., Div. Min. Resources, Min. Invest. 2, pp. 1-14.

Willis, Bailey, and Willis, Robin, 1941, Eruptivity and Mountain Building, Geol. Soc. America Bull., vol. 52, no. 10, pp. 1643-1683.

Winchell, A.N., 1951, Elements of Optical Mineralogy, Part II Description of Minerals, John Wiley and Sons, Inc., 551 pages.