COMMONWEALTH OF VIRGINIA

STATE COMMISSION ON CONSERVATION AND DEVELOPMENT

VIRGINIA GEOLOGICAL SURVEY

ARTHUR BEVAN, *State Geologist*

Bulletin 38

Kyanite in Virginia

Geology of the Kyanite Belt of Virginia

BY

ANNA I. JONAS

Economic Aspects of Kyanite

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STATE COMMISSION ON CONSERVATION AND DEVELOPMENT

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LETTER OF TRANSMITTAL

COMMONWEALTH OF VIRGINIA

VIRGINIA GEOLOGICAL SURVEY

UNIVERSITY OF VIRGINIA

CHARLOTTESVILLE, VA., April 20, 1932.

To the State Commission on Conservation and Development:

GENTLEMEN:

I have the honor to transmit and to recommend for publication as Bulletin 38 of the Virginia Geological Survey series of reports the manuscript and illustrations of a report on *Kyanite in Virginia.* It consists of the *Geology of the Kyanite Belt of Virginia,* by Dr. Anna I. Jonas, and *Economic Aspects of Kyanite,* by Mr. Joel H. Watkins.

This report covers parts of Amelia, Appomattox, Buckingham, Campbell, Carroll, Charlotte, Cumberland, Fluvanna, Goochland, Grayson, Lunenburg, Nottoway, and Prince Edward counties.

The part of the report by Miss Jonas is one of the results of her survey of the Piedmont region of Virginia for the Virginia Geological Survey, with additional information gained from her similar work on the crystalline rocks of the Appalachian region. In it are discussed the geologic occurrence, relations, and origin of the kyanite and kyanite-bearing rocks.

The part of the report by Mr. Watkins is a result of his close observation of and association with the commercial development of kyanite and similar minerals.

As kyanite and similar minerals have large potential uses in the ceramic industries, and as one of the largest known belts of kyanite occurs in Virginia, this report should be of considerable value and interest.

Respectfully submitted,

ARTHUR BEVAN,
State Geologist.

Approved for publication:
State Commission on Conservation and Development,
Richmond, Virginia, June 15, 1932.
RICHARD A. GILLIAM, *Executive Secretary.*

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ABSTRACT

The interest in this report centers in the kyanite-bearing rocks which occur for the most part in Buckingham, Prince Edward and Charlotte counties in central Virginia and in Carroll and Grayson counties in southwestern Virginia. Kyanite is mined in Baker Mountain in southern Prince Edward County. The economic aspects of kyanite are discussed in the second part of the report.

Kyanite in central Virginia occurs for the most part in a metamorphosed sediment, the Wissahickon formation. Where most abundant it is found in the quartzite beds of that formation. Besides forming Baker Mountain the kyanite-bearing quartzite gives rise to Willis, Woods, and Leigh mountains which rise boldly above the upland surface of the country. In southwestern Virginia kyanite occurs in pegmatite.

Kyanite in both types of occurrence is found in a belt of pre-Cambrian crystalline rocks which in Virginia underlie the greater part of two physiographic divisions, the Piedmont and the Blue Ridge provinces. The crystalline belt is 105 miles wide in central Virginia and 240 miles wide on the southern border of the State. Besides pre-Cambrian rocks it contains infolds of Lower Cambrian and upper Ordovician rocks and areas of Triassic sediments.

Kyanite is an aluminous silicate which occurs as a metamorphic mineral formed in the Wissahickon formation under conditions of great heat and pressure during pre-Cambrian time. Kyanite in the pegmatite near Galax in southwestern Virginia is a high-temperature mineral of igneous origin.

The Wissahickon formation in which the kyanite-bearing beds occur is a crystalline schist, a part of the Glenarm series of late pre-Cambrian age. It is an oligoclase-mica schist with quartzite beds formed in the mesozone during pre-Cambrian metamorphism. The formation has in part undergone a second metamorphism in the late Paleozoic orogeny, which resulted in a breaking up of the textures formed in the earlier pre-Cambrian metamorphism and the formation of albite-chlorite muscovite schist.

The Wissahickon formation was intruded in pre-Cambrian time by gabbro, now hornblende gneiss or amphibolite, and by Columbia granite (granodiorite). Pre-Cambrian basic and acid volcanics of the Virgilina area extend into the southern part of the kyanite belt.

The Arvonia slates of late Ordovician age occur in a narrow area lying north and south of James River and are quarried at Arvonia for an excellent grade of roofing slate.

Triassic sediments occur in several small areas in the kyanite belt, the largest area lying north of Farmville. They are westward-dipping red sandstones and shales which unconformably overlie the pre-Cambrian rocks. The whole area is cut by Triassic diabase dikes which strike nearly north.

The kyanite belt of central Virginia is a part of the Appomattox overthrust block. This thrust is a split of a larger overthrust, the Martic, which extends southwest across the Piedmont province of Virginia near Lynchburg and west of Stuart. These overthrusts occurred during late Paleozoic mountain-making movements when the rocks of the kyanite belt were closely folded and overturned to the northwest and the Martic overthrust rode northwestward over the rocks of the Catoctin-Blue Ridge anticlinorium. During this deformation the part of the Wissahickon formation near the soles of the thrusts and the intrusive rocks in the same zones suffered strong differential movement. The late Paleozoic Petersburg granite, which is exposed east of the kyanite belt, was intruded after crustal folding ceased.

Erosion followed this orogeny and in upper Triassic time sediments were deposited in basins localized by tension faulting. The sedimentation was closed by further normal faulting accompanied by diabase intrusion and arching. The block mountains formed in this deformation were peneplained in post-Triassic time. The peneplain was arched in Tertiary time and is now preserved as remnants on the crest of the Blue Ridge.

Kyanite is of widespread occurrence but is of commercial importance in a few places only. Kyanite is mined in Virginia on a small scale in Prince Edward County and is being prospected in Grayson and Carroll counties, near Galax.

Geology of the Kyanite Belt of Virginia

By Anna I. Jonas

INTRODUCTION

Location of the Area

The kyanite-bearing rocks of central Virginia occur in Fluvanna, Goochland, Amelia, Buckingham, Appomattox, Prince Edward, and Charlotte counties. The area shown on the geologic map (Pl. 2) covers about 1,330 square miles and is included in the southeastern part of the Palmyra quadrangle, the southwestern part of the adjoining Buckingham quadrangle, the western two-thirds of the Farmville quadrangle, the Appomattox quadrangle except in the northwestern ninth, and the western edge of the Lynchburg quadrangle. These quadrangles lie between parallels 37° and 38° and meridians 78° and 79°. (See Pl. 1.)

Four railroads cross the area. The James River division of the Chesapeake and Ohio Railway follows the left bank of the James and has branches to Palmyra and Gordonsville and to Rosney. The main line of the Norfolk and Western Railway crosses the southern part of the area and has a belt line from Burkeville to Pamplin by way of Meherrin. The Danville branch of the Southern Railway and the Virginian Railway lie south of the Norfolk and Western Railway.

Field Work

A general reconnaissance of the geology of the crystalline rocks which was made by the writer during the preparation of the geologic map of Virginia, published in 1928, covered the area of the kyanite belt. Detailed work for the present report was done during portions of the years 1929-1931.

A report by Taber[1] deals with the northern part of the area. Furcron[2] has described the western part of the area. Roberts[3] mentions many features of the Triassic sediments north of Farmville. The report by Laney[4] on the Virgilina volcanic belt covers a few square miles of the south-central part of this area.

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1 Taber, Stephen, Geology of the gold belt in the James River Basin, Virginia: Virginia Geol. Survey Bull. 7, 1913.

2 Furcron, A. S., James River iron and marble belt, Virginia: Manuscript in the files of the Virginia Geol. Survey.

3 Roberts, J. K., Geology of the Virginia Triassic: Virginia Geol. Survey Bull. 29, 1928.

4 Laney, F. B., Geology and ore deposits of the Virgilina district of Virginia and North Carolina: Virginia Geol. Survey Bull. 14, 1917.

GEOGRAPHY

TOPOGRAPHY

The kyanite belt lies within the physiographic division of the eastern United States known as the Piedmont province. (See Pl. 1.)) The area is a well-dissected upland whose interstream areas are wide, flat hill summits, broken here and there by long, low hills or mountains. The mountains include Willis Mountain, with an altitude of 1,159 feet; Baker Mountain, 750 feet; and Leigh Mountain, 715 feet; all underlain by kyanite quartzite. Mountains with an altitude of 1,000 to 1,050 feet rise above the upland surface west and northwest of Appomattox Courthouse. The general level of the upland north and south of James River is 500 feet. Appomattox River, which lies between the James and the Roanoke, heads in a divide at 700 to 800 feet. This upland extends southwestward through Dillwyn to Appomattox Courthouse and southeastward to Farmville. Willis Mountain is a narrow ridge with steep rocky sides, which is 2 miles long and rises 400 feet above this upland surface. It can be seen for many miles.

DRAINAGE

The master streams are James and Appomattox rivers, which flow eastward through the area, and Roanoke River which crosses the southwest corner. Only Appomattox River heads in this area. The rivers have a steep fall; that of the James is 0.83 foot to the mile, and that of the Appomattox is 1.03 feet to the mile in 45 miles. Both streams flow across the structural trend and developed their courses before the present valleys were formed. Rivanna River and Byrd Creek are the main tributaries of the James from the north, and Slate and Willis rivers flow into it from the south. Buffalo and Briery creeks enter Appomattox River near Farmville; Falling River, Cub Creek, and Little Roanoke River flow south into Roanoke River. Meherrin River heads in the southeastern part of the area.

OUTLINE OF THE GEOLOGY OF THE PIEDMONT AND BLUE RIDGE PROVINCES

The kyanite-bearing rocks of central Virginia occur in a belt of pre-Cambrian crystalline schists which crop out in the eastern part of the Piedmont province. The term Piedmont is physiographic and in Virginia is applied to the upland region extending from the western border of the Coastal Plain westward to the eastern edge of the Blue Ridge province. (See Pl. 1.) The entire area from the western border of the Coastal Plain to the west front of the Blue Ridge is underlain by metamorphosed pre-Cambrian rocks of sedimentary and igneous origin, above which in places are Lower Cambrian quartzites, Ordovician slate, and Triassic sediments. The rocks of the Martic overthrust block[5] occupy the eastern part of this crystalline belt, and those of the Catoctin-Blue Ridge anticlinorium the western part. The boundary between these two geologic divisions in northern Virginia is formed by the western border faults, of Triassic age, which extend through Leesburg east of the Bull Run Mountains and southwestward through Gordonsville to Lynchburg. These normal faults have dropped the rocks of the Martic thrust block and the overlying Triassic sediments with respect to the rocks of the Catoctin-Blue Ridge anticlinorium lying west of these normal faults. Southwest of Lynchburg the fault contact of the Martic thrust block on the rocks of the Catoctin-Blue Ridge anticlinorium has not been modified by later Triassic faulting.

The Piedmont province, therefore, includes the rocks of the Martic thrust block and the eastern part of those of the Catoctin-Blue Ridge anticlinorium.[6] The term Piedmont does not apply to any belt of uniform structure or geology.

MARTIC THRUST BLOCK

The Martic thrust block is composed for the most part of pre-Cambrian rocks of sedimentary and igneous origin. In Virginia it includes (1) the Glenarm series, of pre-Cambrian age and younger than the Baltimore gneiss, which comprises from the base upward the Setters quartzite, Cockeysville marble, and Wissahickon formation; (2) pre-Cambrian intrusive and extrusive rocks; and (3) the Ordovician Arvonia slate.[7]

[5] Jonas, A. I., Metamorphic belt of the Appalachians: Geol. Soc. of America Bull., vol. 40, pp. 507-10, 1929.

[6] Jonas, A. I., Geologic reconnaissance in the Piedmont of Virginia: Geol. Soc. America Bull., vol. 38, pp. 843-845, 1927.

[7] Knopf, E. B., and Jonas, A. I., Baltimore County: Maryland Geol. Survey, pp. 99-105, 140-191, 1929.

CATOCTIN-BLUE RIDGE ANTICLINORIUM

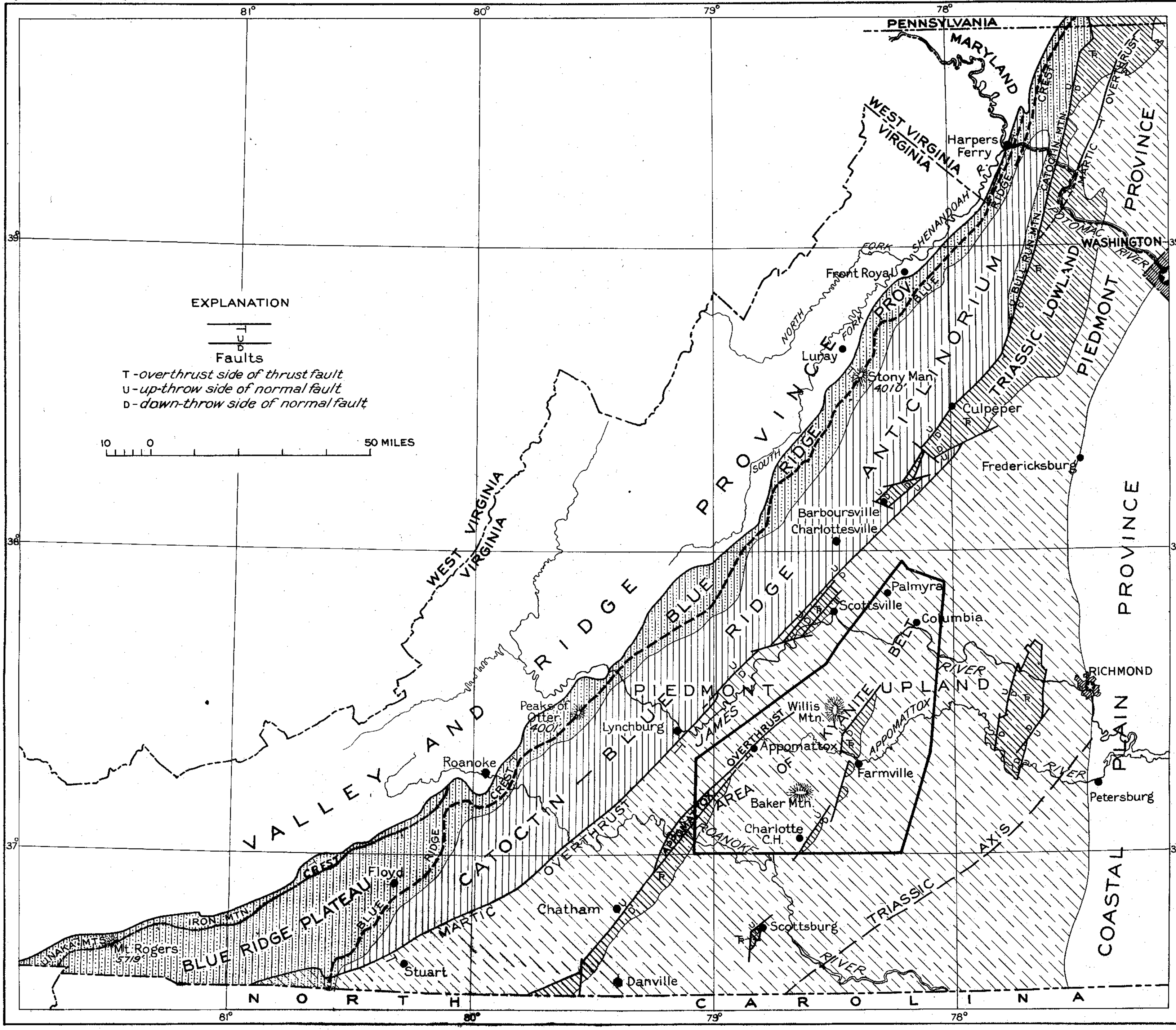
The Catoctin-Blue Ridge anticlinorium has a core of pre-Cambrian Lynchburg gneiss, a biotite schist and gneiss of sedimentary origin lithologically similar to the mesozone facies of the Wissahickon formation of Maryland and Pennsylvania. It contains many pre-Cambrian intrusive rocks, both older and younger than the basic flows now exposed on both flanks of the anticlinorium northeast of Lynchburg. Lower Cambrian quartzite overlying these pre-Cambrian rocks is exposed along the western edge and along part of the eastern edge of the anticlinorium. Still younger Paleozoic rocks deposited in the area of the anticlinorium when it was part of the Appalachian geosyncline have been removed by erosion in Virginia, but farther northeast they are preserved in infolded synclinal valleys lying between the anticlinal uplifts.

ORIGIN OF FEATURES

In the area of the Catoctin-Blue Ridge anticlinorium and Martic overthrust block, late Paleozoic deformation produced great folds whose axes were pushed northwestward to a nearly horizontal position and flat thrust faults that are related to the breaking of these overturned folds. As a result the area west of the Coastal Plain consists of a series of great rock slices driven westward one over another. The Martic thrust block has ridden over the east side of the Catoctin-Blue Ridge anticlinorium, which in turn is overthrust on the Paleozoic rocks west of it. The rocks on the soles of these thrusts underwent metamorphism, largely retrogressive,[8] producing phyllonitization and mylonitization of the pre-Cambrian mesozone schists and mylonitization of the igneous rocks.

Late in the period of Appalachian mountain making, the late Paleozoic granite, including the Woodstock granite of Maryland, the Petersburg granite of Virginia and other granites to the southwest, was intruded into the core of the Permian mountains along the inner or eastern side. After these folded mountains were denuded to their roots, Triassic sediments were deposited in down-faulted basins within the area of the Catoctin-Blue Ridge anticlinorium and the Martic overthrust. The history of this area since the block faulting and differential uplift that ended the Triassic period has been one of erosion interrupted by uplift and tilting.

[8] Knopf, E. B., Retrogressive metamorphism and phyllonitization: Am. Jour. Sci., 5th ser., vol. 21, pp. 1-27, 1931.



MAP SHOWING LOCATION OF THE KYANITE BELT OF CENTRAL VIRGINIA, PHYSIOGRAPHIC PROVINCES AND GEOLOGIC DIVISIONS OF THE CRYSTALLINE AREA.

Catoctin-Blue Ridge anticlinorium, vertically ruled; Martic overthrust block diagonally ruled; Triassic sediments, denser diagonal ruling; Blue Ridge province, dot pattern over vertical ruling.

DESCRIPTION OF THE ROCKS

PRE-CAMBRIAN ROCKS OF SEDIMENTARY ORIGIN

WISSAHICKON FORMATION

DEFINITION AND CHARACTER

The Wissahickon formation is the oldest rock of the area and was the sediment into which the pre-Cambrian igneous rocks of this area were intruded. (See Table 1.) The Wissahickon formation[9] by definition consists of oligoclase-biotite-muscovite gneiss and schist and micaceous quartzite. The chief constituents are oligoclase, biotite, muscovite, and quartz, with a variable content of garnet, staurolite, and kyanite. From its complete recrystallization and the presence of such minerals as garnet, staurolite, and kyanite it is evident that the present condition of the formation has been developed by metamorphic agencies characteristic of a deep-seated zone. This metamorphism took place in pre-Cambrian time, but the formation was subjected in part to metamorphism during the late Paleozoic diastrophism, and much of it in the kyanite belt is a biotite-chlorite or a muscovite-chlorite schist and phyllonite. The variation in the metamorphic facies[10] of the Wissahickon formation and their distribution are discussed farther on.

DISTRIBUTION

The Wissahickon formation occurs north of James River in an area which extends northeast of Columbia and is bordered on three sides by the Columbia granite. A larger area lies west of the Columbia granite and extends southwestward until the granite cuts it off in the southwestern part of the kyanite belt. On James River the formation is exposed from Bremo station westward and contains areas of intrusive hornblende gneiss and the infolded Arvonia slate. The Wissahickon schist lies between areas of the Columbia granite from the region east of Green Bay to Briery. (See Pl. 2.)

Fresh outcrops are not plentiful, because of deep weathering and because the older roads and all the railroads except the Virginian follow the interstream upland surface, conforming to its windings and avoiding stream valleys as much as possible. The best outcrops occur in deeper cuts of the new State highways which cut across country regardless of topography, in the cuts of the low-grade Virginian Railway, and along the James, Rivanna, and Roanoke rivers. The newer highways with fresh road cuts include No. 310 from Farmville to Cumberland Courthouse, No. 60 from Farmville to Burkeville, No. 501 from Keysville to Burkeville, No. 13 from Bent Creek eastward through Buckingham Courthouse and Ca Ira, No. 15 passing south through Palmyra to Bremo and Dillwyn, and No. 20 from Charlotte Courthouse to Brookneal.

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[9] Knopf, E. B., and Jonas, A. I., Geology of the McCalls Ferry-Quarryville district, Pennsylvania: U. S. Geol. Survey Bull. 799, pp. 25-27, 1929.

[10] Eskola, Pentti, Mineral facies of rocks, Norsk. Geologisk Tidsk., 6, pp. 143-194, 1920.

TABLE 1.—*Rocks of the Piedmont and Blue Ridge provinces, Virginia*

Blue Ridge-Catoctin Mountain anticlinorium	Martic thrust block
UPPER TRIASSIC	
(Sedimentary and intrusive rocks)	
LATE PALEOZOIC	
	Petersburg granite (including "Red Oak granite" and "Leatherwood granite")
UPPER ORDOVICIAN	
	Arvonia slate Quantico slate (sedimentary, including some rhyolite)
LOWER CAMBRIAN	
Weverton quartzite Loudoun formation	
PRE-CAMBRIAN	
(Sedimentary and igneous rocks)	
Felsite (dikes) Blue quartz pegmatite (albitite) Marshall granite Catoctin greenstone } extrusive Aporhyolite } extrusive Hypersthene granodiorite Metagabbro-metaperidotite group Lovingston granite gneiss	Pegmatite Columbia granite (including Shelton granite gneiss facies) Greenstone } Virgilina volcanic group Aporhyolite } Virgilina volcanic group Metagabbro-metaperidotite group
Lynchburg gneiss White marble	Glenarm series: Wissahickon formation Glenarm series: Cockeysville marble Glenarm series: Mount Athos quartzite Glenarm series: Greenstone volcanics (extrusive)

OLIGOCLASE-MICA SCHIST

The oligoclase-biotite-muscovite schist and gneiss facies of the Wissahickon formation is exposed west of Phenix on highway 20 and on the Virginian Railway, south of Prospect on Falling Creek at the crossing of highway 305, and northwest of Prospect near Appomattox River. Six miles southwest of Appomattox Courthouse there is an area of biotite schist and gneiss, bordered on the east and north by retrogressive muscovite-chlorite schist, which extends southwestward in a widening belt.

The oligoclase-biotite-muscovite schist exposed west of Phenix is a medium-grained rock with alternations of gneissic and schistose layers and is bent into recumbent folds overturned to the northwest. Under the microscope it is seen to be a granoblastic rock composed of oligoclase, quartz, brown biotite, and muscovite, with garnet, kyanite, magnetite, zircon, and apatite. (See Pl. 3, A.) It is a schist formed under conditions of high temperature and pressure in the mesozone. It resembles in metamorphism and mineral composition the Wissahickon schist and gneiss of the type locality in Pennsylvania.

South of Prospect, on Falling Creek, there is a coarse-grained sparkling biotite-muscovite schist with abundant garnet, kyanite, staurolite, and tourmaline. Thin sections show that the quartz has strain shadows and some granulation. Deep-brown biotite blades containing inclusions of zircon with wide pleochroic haloes, muscovite, staurolite, garnet, kyanite, and abundant magnetite make up the rock. It resembles the rock west of Phenix but is coarser grained and somewhat cataclastic.

The biotite-muscovite schist that occurs northwest of Prospect on Appomattox River near Beazley's ford is coarse grained. A thin section shows muscovite, biotite and some chlorite secondary to it, feldspar, and quartz. The feldspars are in large part sericitized. The biotite and chlorite contain inclusions of zircon with pleochroic haloes. Where zircon crystals are found on the boundary line of biotite and chlorite, so that the surrounding pleochroic halo lies partly in each mineral, the halo is paler in the chlorite than in the biotite. Because chlorite is more sensitive to the darkening effect of radioactive emanations that produce the haloes, the occurrence of a more advanced halo in biotite is taken as evidence that the chlorite was formed later than the biotite. The rock is therefore diaphthoritic. (See Pl. 3, B.)

The biotite gneiss in the area southwest of Appomattox Courthouse shows some deformation in undulatory extinction of quartz but no retrogression.

DIAPHTHORITIC FACIES[11]

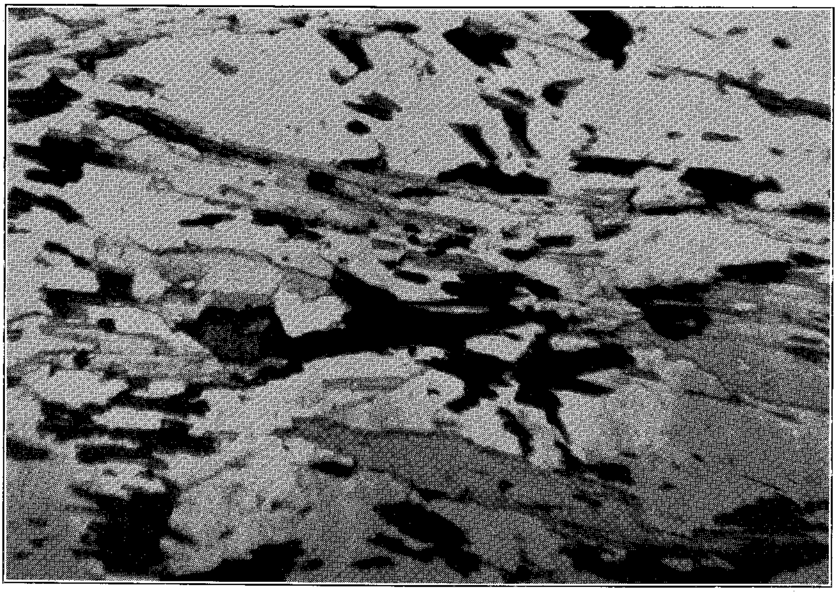
A very cataclastic biotite gneiss occurs in a small area surrounded by muscovite-chlorite schist 3 miles northwest of Oakville on Wreck Is-

[11] Knopf, E. B., op. cit., pp. 4-9, 1931.

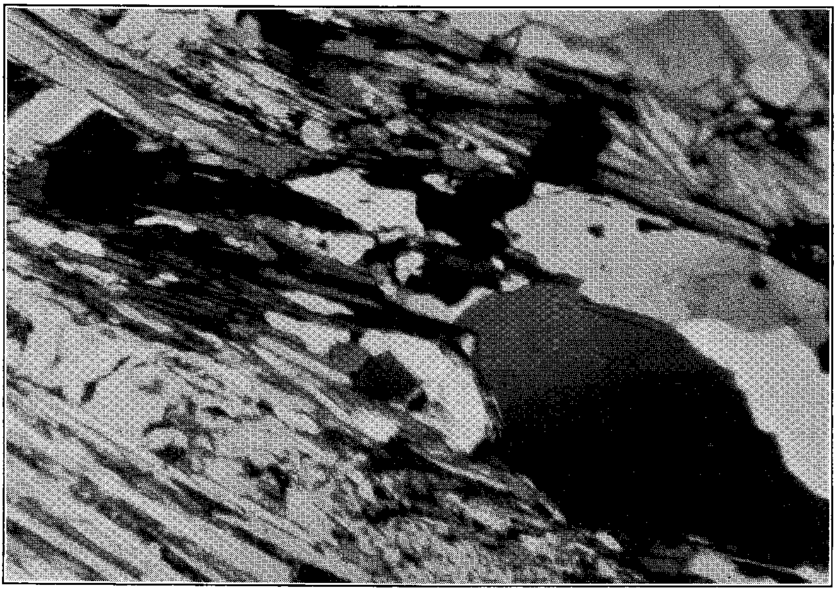
land Creek, outside of the area of the kyanite belt. It is a banded garnetiferous biotite gneiss with hornblendic layers. The quartz is granulated; the feldspar (albite) is broken and dusted with black inclusions; the biotite is bleached and altered to chlorite and both contain abundant pleochroic haloes around zircon inclusions. The deep-brown biotite occurring as porphyroblasts across the schistosity is helicitic, preserving wavy lines of black dust inclusions, the layering of which antedated the formation of the porphyroblasts. Subsequent intense differential movement resulted in the degradation of the porphyroblastic structure of the rock and formed a foliation transverse to the older foliation and to the larger biotite crystals. The presence of chlorite formed from biotite indicates that retrogressive metamorphism accompanied cataclasis.

The greater part of the Wissahickon formation of the kyanite belt is more altered by late Paleozoic deformation than the biotite-muscovite schist and gneiss of the areas already described. The most easterly area of Wissahickon in the kyanite belt is best exposed on South Anna River northeast of the area included on the geologic map. (See Pl. 4, A.) At that locality it is a fine-grained biotite schist with abundant garnets. The thin section shows that the layers are made up of many thin bleached and twisted biotite blades banded with black dust. The biotite bends around the garnets, which are granulated, and around lenslike areas of biotite and quartz and scanty albite. Deep-brown pleochroic biotite older than the schistosity occurs in large blades containing inclusions of zircon and black dust in a helicitic network, which preserves a layering that was present in the rock before the formation of the biotite. Pleochroic haloes surround the zircons and some of the dust specks. The biotite has been altered in part to chloritoid during the development of the younger schistosity, which is formed by the thin bleached biotite blades.

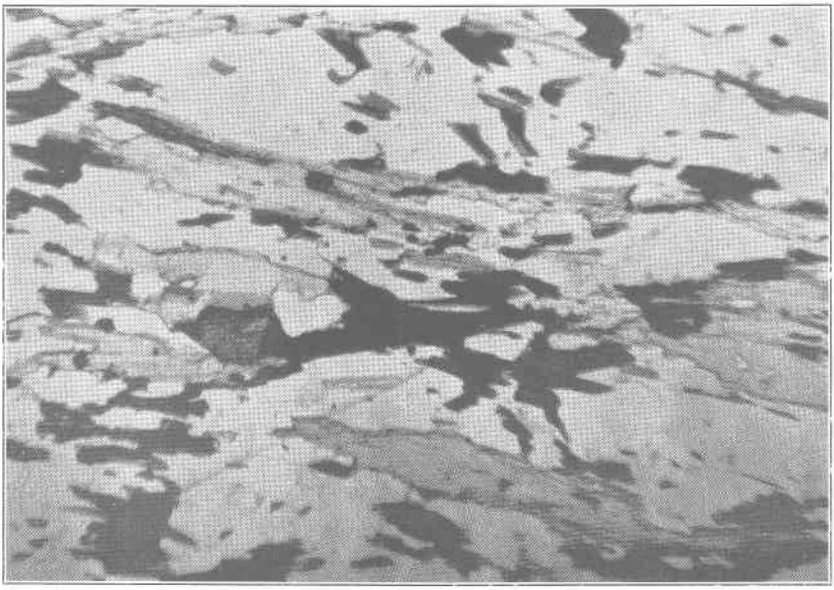
The next area of Wissahickon to the west, which lies 4 or 5 miles west of Columbia and west of the Columbia granite, extends southwestward from the vicinity of Carysbrook across James River near Bremo Bluff, and southwestward through Willis Mountain to a point east of Prospect. The formation is well exposed on both sides of James River from Bremo station to the area of Arvonia slate at Slate River. It consists of biotite quartzite interbedded with garnetiferous biotite, phyllonite. (Pl. 4, B.) These rocks are closely folded, and at Bremo Bluff the thick quartzite beds, which stand nearly vertical in an anticline, form cliffs on both sides of James River and produce falls in the stream where they cross it. The quartzite is fine grained and is made up largely of quartz and fine albite, with blades of brown and green biotite altered to chlorite, and muscovite and zircon. It contains much secondary siderite, in common with the other rocks of that area. The garnetiferous biotite schist with which the quartzite is interbedded looks in a hand



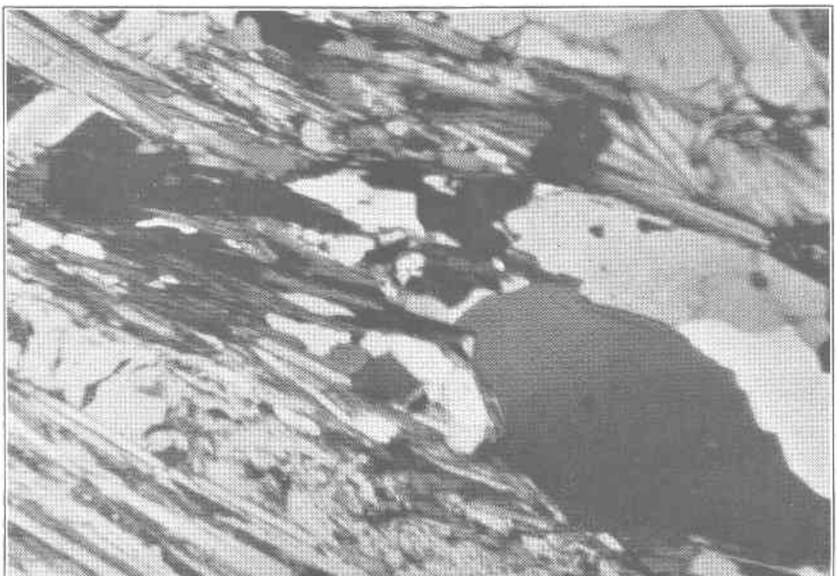
A. Oligoclase-biotite-muscovite schist from west of Phenix, Charlotte County. Plain polarized light; X 38.



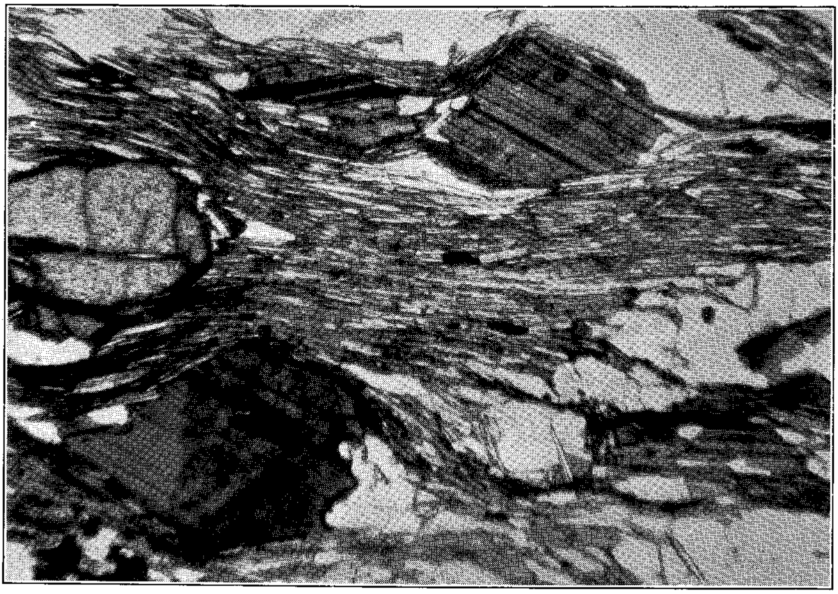
B. Biotite-muscovite schist from northwest of Prospect on Appomattox River, Prince Edward County. Shows cataclastic and sericitized feldspar. Plain polarized light; X 38.



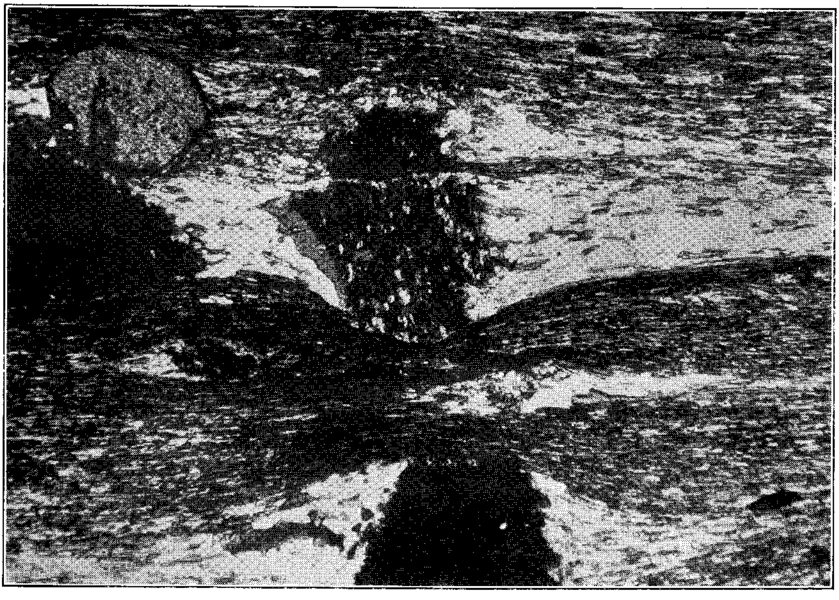
A. Oligoclase-biotite-muscovite schist from west of Phenix, Charlotte County. Plain polarized light; X 38.



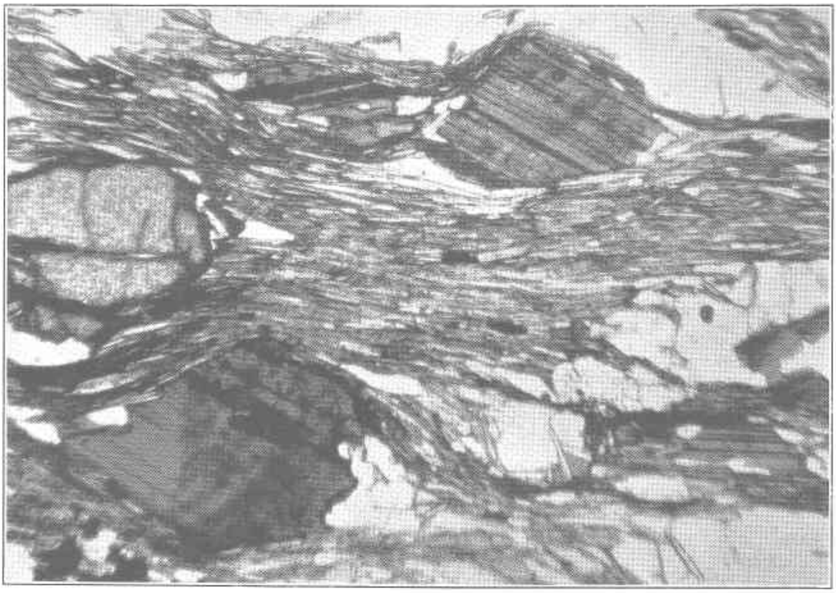
B. Biotite-muscovite schist from northwest of Prospect on Appomattox River, Prince Edward County. Shows cataclastic and sericitized feldspar. Plain polarized light; X 38.



A. Garnetiferous biotite schist from South Anna River. Shows helicitic texture in biotite porphyroblasts and fractured garnet with the foliation bending around them. Plain polarized light; X 38.



B. Fine-grained garnetiferous biotite phyllonite, from Bremo Bluff, on James River. Shows ragged biotite porphyroblasts in lenslike areas of quartz and feldspar. Foliation formed by fine biotite blades and black dust. Plain polarized light; X 38.



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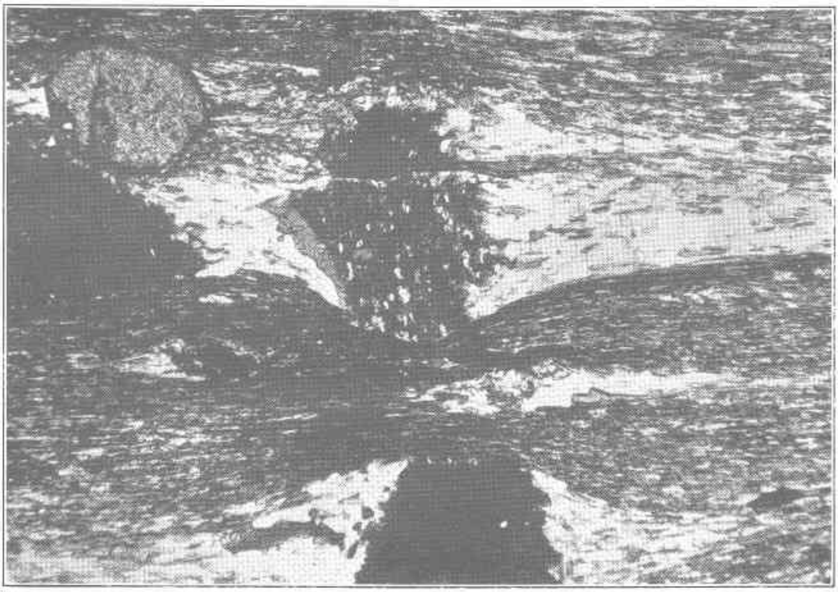
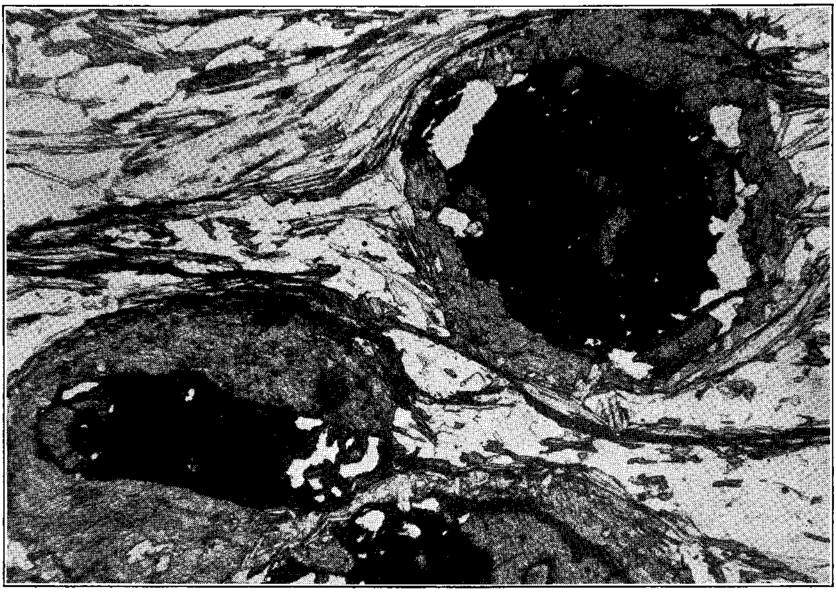
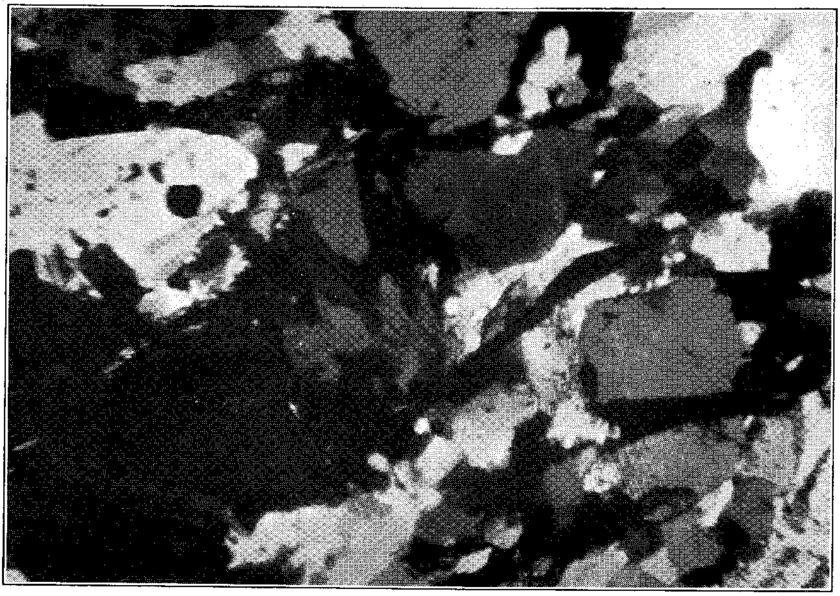


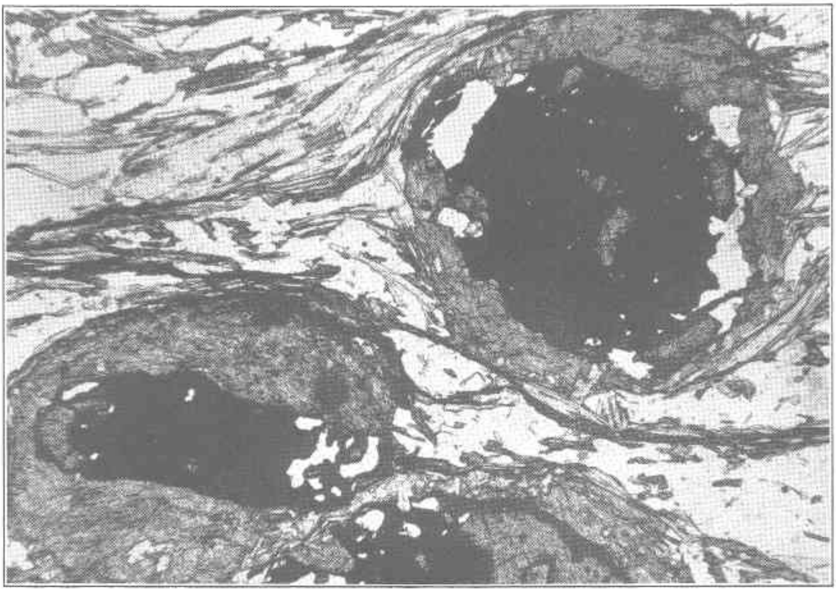
B. Fine-grained garnetiferous biotite phyllonite, from Bremo Bluff, on James River. Shows ragged biotite porphyroblasts in lenslike areas of quartz and feldspar. Foliation formed by fine biotite blades and black dust. Plain polarized light; X 38.



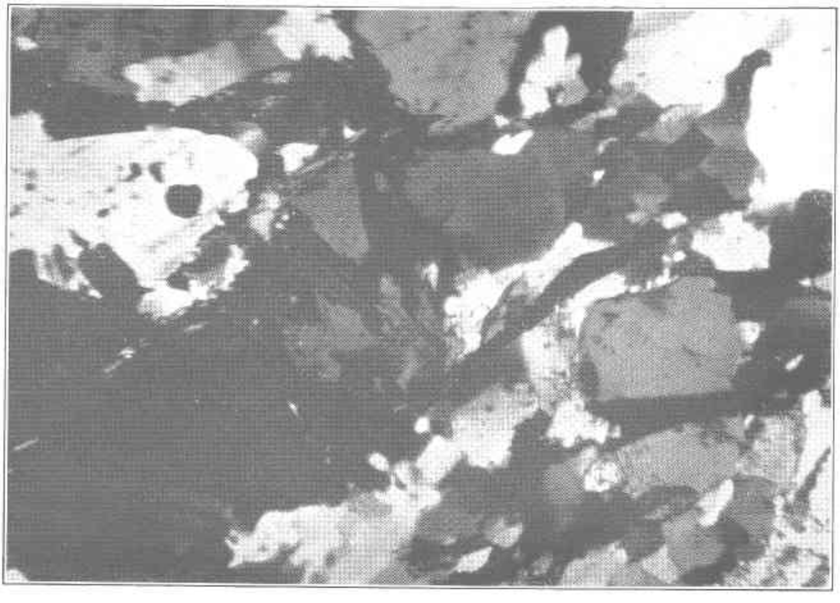
A. Diaphthoritic garnetiferous mica schist from Crane Creek, south of Hixburg, Appomattox County. The garnet cores are enclosed in a shell of chlorite and are in part weathered to limonite (black). Plain polarized light; X 38.



B. Columbia granite near Cub Creek east of Red House, Charlotte County. Plain polarized light, crossed nicols; X 38.



A. Diaphthoritic garnetiferous mica schist from Crane Creek, south of Hixburg, Appomattox County. The garnet cores are enclosed in a shell of chlorite and are in part weathered to limonite (black). Plain polarized light; X 38.



B. Columbia granite near Cub Creek east of Red House, Charlotte County. Plain polarized light, crossed nicols; X 38.

Kyanite quartzite from Baker Mountain, Prince Edward County. Kyanite blades are deep blue in a matrix of white quartz. Natural size.

Kyanite quartzite from Baker Mountain, Prince Edward County. Kyanite blades are deep blue in a matrix of white quartz. Natural size.

specimen like a silky slate studded with biotite and garnet. These schists were called "knotted schist" by Taber.[12] Field evidence shows that the dominant structure of the schist is a younger foliation, formed during the late Paleozoic deformation, which has in part or entirely transposed the older foliation of the schist but not that of the interbedded massive quartzite. In thin section the schist is seen to be composed of muscovite and fine black dust forming the schistosity. Biotite porphyroblasts like those in the rock from South Anna River are variously oriented with ragged outline and preserve a helicitic network. They occur in lenses with quartz that was crystallized during the rotation of the biotite and the development of these lenses parallel to the younger dominant schistosity. The biotite contains inclusions of quartz and of zircon with pleochroic haloes. Some of the garnets are altered in part to chlorite. The younger foliation is so perfect and the rock so fine grained that it resembles a slate of progressive metamorphism.

The quartzite beds become less massive southwest of James River, and thin quartzite interbedded with sparkling muscovite-quartz schist forms the ridge passing through Alpha and Dillwyn. This muscovite-quartz schist is a fine-grained rock composed of quartz, twisted and sliced muscovite fibers with no trace of biotite, and black dust too fine for identification. The muscovite-quartz schist extends southward to Willis Mountain, which is made up of a massive quartzite containing blue to gray blades of kyanite with a little muscovite and hematite. On weathering this rock becomes a reddish saccharoidal quartzite with kyanite blades. The mountain is 3 miles long in the direction of the strike and has abrupt rocky sides 100 feet high. A lower parallel ridge of kyanite quartzite lies to the east of it.[13] In thin section the quartz shows undulatory extinction and the kyanite is broken. The kyanite quartzite of Willis Mountain is in strike with the biotite-muscovite schist south of Prospect, already described. (See Pl. 2.)

The Wissahickon schist west of Willis Mountain extends southwestward across Appomattox River, where it is a diaphthoritic garnet-muscovite schist, through Madisonville, where it is a kyanite quartzite, and southwestward into the oligoclase-mica schist and gneiss facies west of Phenix. The Baker Mountain kyanite quartzite area lies 1 mile east of Madisonville and is surrounded by the Columbia granite.

The belt of Wissahickon west of the Arvonia slate exhibits metamorphic and lithologic variations along the strike similar to those already described. It is a garnetiferous muscovite schist with kyanite quartzite beds. Kyanite quartzite is exposed in Woods Mountain. The garnetiferous schist from a fresh exposure on Crane Creek south of Hixburg is a silvery green mica schist with a pronounced younger foliation. The thin section shows green biotite wrapping the garnets between

[12] Taber, Stephen, op. cit., pp. 29-34.
[13] Taber, Stephen, op. cit., pp. 27-28, 113-114.

layers of fine quartz and of chlorite secondary to biotite. (See Pl. 5, A.) The garnets are broken, contain quartz and feldspar inclusions, and have borders of chlorite which is a retrogressive alteration product from the garnet. The relict garnet cores are weathered in part to limonite, which forms a band between fresh garnet and chlorite. The chloritization is an epizone process, which took place during the late Paleozoic metamorphism, but the formation of limonite is the result of later surface weathering. Along the strike near Pamplin the muscovite quartzite beds are finely cataclastic and resemble the fine-grained, straight-layered mylonitized granite that lies to the west.

The next belt of Wissahickon toward the west is less than 1 mile wide between two bands of the Shelton granite gneiss facies of the Columbia granite. Mica schist of this belt, freshly exposed on Falling and Roanoke rivers, is greenish gray and shows a wavy schistosity that dips steeply southeast, parallel to the schistosity in the adjoining Shelton granite gneiss. The biotite wraps around lenslike areas of quartz and feldspar, is brown to green and colorless, and is in part altered to chlorite. The garnets are older than the foliation.

The Wissahickon formation to the west of this mica schist is a chlorite-muscovite schist and quartzite, which is cataclastic and diaphthoritic, with incipient to perfect cleavage developed across the older structure of the rock. It extends southwestward through Palmyra, Hardware station, Buckingham Courthouse, and Spring Mill. North of Palmyra and on James River near Hardware station it is a quartzose banded green albite schist, closely folded and with an imperfect development of younger foliation cutting the older. The rock is diaphthoritic, containing biotite altered to chlorite. Quartz, albite, and epidote are the other constituents. It is interbedded with a quartzite containing blue quartz grains. Near Palmyra it contains much secondary siderite.

Southwestward along the strike near and beyond Buckingham Courthouse the schist becomes finer grained and the younger foliation is better developed on the limbs of the close folds, with the older foliation still preserved in arches of the folds. The rock is a phyllite-mylonite or phyllonite derived from a coarser grained schist during differential movement. Diaphthoresis or reversion of metamorphism has accompanied the mylonitization. Six miles southwest of Appomattox Courthouse this phyllonite ends abruptly to the northwest against the area of biotite-muscovite schist and gneiss lying south of Pilot Mountain, already described. The contact is the western edge of the Appomattox thrust fault, along which the albite-chlorite-muscovite schist, or phyllonite, has ridden westward over Wissahickon biotite schist and gneiss. This thrust fault is a break in the larger Martic thrust block, whose western edge lies west of James River and the kyanite belt. (See Pl. 1.) The southwestward extent of the Appomattox overthrust is described in the section on structure.

The Wissahickon biotite gneiss and schist of the area west of the Appomattox thrust widens southwestward and extends across Virginia through Chatham. The biotite schist and gneiss on the northern and western sides grade into biotite-muscovite-chlorite schist with a retrogressive metamorphism. The schist becomes finer grained and more deformed and phyllitic westward near the edge of the Martic overthrust. The belt of retrogressive schist directly north and west of the biotite gneiss and schist passes through Spout Spring, Long Mountain, and Rustburg and crosses Roanoke River at Alta Vista. Near Spout Spring there is a coarse biotite-muscovite-staurolite schist in which staurolite is altered to muscovite and chlorite. In thin section the rock is seen to be made up of poikilitic metacrysts of albite with inclusions of biotite, garnet, and quartz. The staurolite is broken and altered along the edges and cracks to muscovite and chlorite; garnet also is broken. This rock grades westward and northwestward on the western edge of the kyanite belt into a closely folded muscovite-chlorite schist in which biotite, garnet, and staurolite have been partly or entirely altered to the epizone mineral chlorite and which contains a prominent younger foliation dipping steeply southeast that breaks up the older folded schistosity. This rock resembles the phyllonite to the east, on the western edge of the Appomattox thrust east of Appomattox and southward through Spring Mill.

SUMMARY

The Wissahickon formation is an oligoclase-biotite schist and gneiss containing garnet, staurolite, and kyanite formed in the mesozone during pre-Cambrian metamorphism. In the kyanite area it has been altered in large part by a later metamorphism in the epizone during late Paleozoic diastrophism.[14] Different belts across the strike and different parts of the same belt along the strike have been affected differently. All gradations occur from (1) a coarse-grained oligoclase-mica schist in which biotite, staurolite, and garnet are only slightly altered to chlorite and in which the younger foliation is poorly developed, to (2) fine-grained cataclastic schist, or phyllonite, composed of muscovite and chlorite, which contains little or no original biotite, staurolite, or garnet and in which the feldspar is albite. This phyllonite with the typomorphic minerals of the epizone has a steeply dipping foliation that was formed by a refolding of the schist into tightly compressed folds, which broke on the limbs, and resulted in a transposition of the older foliation present in the oligoclase-mica schist facies of the Wissahickon formation.

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[14] Suess, F. E., A suggested interpretation of the Scottish Caledonide structure: Geol. Mag., vol. 68, pp. 77-78, 1931.

KYANITE

Occurrence.—Kyanite occurs as an accessory mineral throughout the Wissahickon formation east of the western belt of the Shelton granite gneiss facies of the Columbia granite. Beds rich in kyanite may be grouped into five areas—north of James River northeast of Columbia, and in Leigh, Willis, Woods, and Baker mountains and vicinity. The Baker Mountain area is the only one in which kyanite has been mined commercially.

Origin.—Kyanite is an aluminum silicate ($Al_2O_3.SiO_2$). It occurs in the Wissahickon formation as a metamorphic mineral[15] formed under conditions of great heat and pressure during pre-Cambrian time, and where it is very abundant it is the result of metamorphism in beds originally rich in alumina. It has been suggested[16] that the formation of kyanite in the area under discussion may be due to the contact action of the Columbia granite. The wide occurrence of kyanite in the Wissahickon formation and the fact that it is not restricted to contact zones render this explanation unlikely. Kyanite occurs also in small amount in pegmatite and gold-bearing veins in this area and in larger quantity in pegmatite in southwestern Virginia, near Galax. In these occurrences it is a high-temperature mineral of igneous origin.

Kyanite in the Wissahickon formation in central Virginia.—Kyanite is present in small amount[17] in quartzite and muscovite schist from Stage Junction northeastward.

In the Willis Mountain belt kyanite quartzite occurs in five parallel belts. From east to west they are the Trent farm,[18] an area 5 miles east of Dillwyn, an area that passes through the Ayre tract and crosses highway 13 east of Rosney, the double peaks of Willis Mountain, and an area 2 miles west of Willis Mountain. The quartzite of Willis Mountain is made up almost entirely of long blades of blue to gray kyanite and grains of quartz. The surface rock is weathered to a red to purple porous quartzite due to the oxidation of the pyrite that is present in the fresh rock and the concentration of iron solutions on the surface of the rock. The south end of the mountain is formed of a massive quartzite containing little kyanite, which does not extend south of Sheppard.

Woods Mountain, 8 miles southwest of Willis Mountain, is formed of quartzite with a smaller kyanite content than that in the quartzite of Willis Mountain. The mountain is about 2 miles long and forms a peak that is especially abrupt on the southwest side, where Appomattox River has cut into it. Southwestward the kyanite quartzite is thinner bedded and becomes a thin muscovite quartzite with a little kyanite

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15 Suess, F. E., op. cit., p. 77.
16 Taber, Stephen, op. cit., p. 27.
17 Taber, Stephen, op. cit., p. 22.
18 Idem., pp. 26-29.

to a point south of Roland Hill, where it is cut off by the Columbia granite.

The Baker Mountain kyanite area is in strike with Willis Mountain and lies 20 miles to the southwest. The mountain is made up of quartzite very rich in kyanite (Pl. 6.), whose commercial importance is discussed in the second part of this report. In the same belt 2 miles farther west, at Madisonville, kyanite quartzite occurs in an area of muscovite-quartz schist.

Kyanite has been found in the Leigh Mountain area in four places but nowhere in large quantity. The quartzite forming Leigh Mountain and some of the muscovite-quartz schist east of Green Bay at Meherrin and north of Briery station are kyanite-bearing.

The kyanite from Baker Mountain is singularly free from alteration, but that on the Trent farm, in the area east of Rosney, and at Madisonville is in part altered to muscovite. It is possible also that some of the muscovite in the muscovite-quartz schist is secondary to original kyanite.

Kyanite in schist elsewhere.—Kyanite occurs in the biotite-oligoclase schist facies of the Wissahickon formation in Pennsylvania and Maryland.[19] It has been described by Watson[20] as present in northern Virginia north of Chancellorsville in strike with the kyanite belt of central Virginia. To the southwest it occurs in muscovite schist in western Halifax County, Va., and has been reported in Barnett Mountain, in Pearson County, N. C.

Farther south in southern North Carolina, along the same strike, kyanite quartzite forms Clubb and Crowder mountains, the Pinnacle, and other ridges in the Kings Mountain area.[21] This kyanite quartzite occurs along the same strike as the kyanite belt of Virginia and is associated with a muscovite-chlorite schist containing staurolite (Battleground schist). This schist is intruded by granite gneiss, augen gneiss, and granite mylonite (Bessemer granite) which resembles the Shelton granite gneiss facies of the Columbia granite and which extends to a point south of Mocksville, N. C., 40 miles northeast of the Kings Mountain area. These rocks in North and South Carolina lie east of biotite gneiss and schist (Carolina gneiss) which form the southwestward continuation of the Wissahickon biotite gneiss and schist of the area southwest of Appomattox and west of the Appomattox overthrust in the Virginia kyanite belt.

During a reconnaissance of the southern Appalachian region in 1930-31 by G. W. Stose and the writer for the geologic map of the

[19] Knopf, E. B., and Jonas, A. I., Baltimore County: Maryland Geol. Survey, pp. 169-170, 1929.

[20] Watson, T. L., Mineral resources of Virginia, Virginia-Jamestown Exposition Commission, p. 388, 1907.

[21] Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Gaffney-Kings Mountain folio (No. 222), p. 5, 1931.

United States,[22] the Appomattox overthrust, the Wissahickon muscovite-chlorite schist and Shelton granite gneiss on its western edge, and the Wissahickon mica gneiss and schist were traced from Virginia across North Carolina and southwestward. The writer concluded that the kyanite quartzite and the Blacksburg schist, called Cambrian by Keith, and the muscovite-chlorite schist (Battleground schist), called pre-Cambrian by him, are all parts of the Wissahickon formation. During late Paleozoic deformation a large part of the Wissahickon formation was altered by intense differential movement in the Appomattox overthrust to a retrogressive phyllonite and areas of granite were sheared out along the fault plane into augen gneiss and granite mylonite. The Blacksburg and Battleground schists are phyllonites formed during overthrusting. The Bessemer granite, which is similar to the Shelton granite gneiss, was mylonitized in this diastrophism. The mesozone biotite schist, over which the Appomattox overthrust rides, is called Carolina gneiss in the Kings Mountain area. The Appomattox thrust was traced into South Carolina to a locality southwest of Spartanburg, where it and the muscovite-chlorite schists on its western edge are cut across by late Paleozoic granite, which is similar to the Yorkville granite of the Kings Mountain area and the Petersburg granite of Virginia.

In eastern Georgia, kyanite quartzite forms Graves Mountain, in Lincoln County near the Wilkes County line, 5 miles southwest of Lincolnton. The quartzite shows evidence of mashing,[23] and the alteration of kyanite to muscovite is one of retrogressive metamorphism. The schistose quartzite was called itacolumite by Shepard,[24] who first described the occurrence.

Kyanite occurs widely in North Carolina in the Blue Ridge, especially in Yancey and Buncombe counties, and farther southwest in Georgia. It has been described as occurring disseminated in the country rock, in veins, and in lenses.[25]

Kyanite in pegmatite in central Virginia.—Kyanite has been found in pegmatite in the central Virginia belt, 4 miles north of Jetersville, west of Madisonville and Hixburg. The blades are small and not abundant. It has been noted by Taber[26] in the gold-bearing vein of the Young American mine, 1½ miles north of Lantana. He concludes that the kyanite, like the veins, is of magmatic origin and came from below as residual material from a granite magma.

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[22] U. S. Geol. Survey, in press (1932).

[23] Watson, T. L., and Watson, J. W., A contribution to the geology and mineralogy of Graves Mountain, Georgia: Univ. of Virginia Philos. Soc. Bull., sci. ser., vol. 1, pp. 200-221, 1912.

[24] Shepard, C. U., On lazulite, prophyllite, and tetradymite in Georgia: Am. Jour. Sci., vol. 27, pp. 36-40, 1859.

[25] Greaves-Walker, A. F., Cyanite in North Carolina: Eng. and Min. Jour., vol. 129, no. 4, pp. 173-174, February 24, 1930.
Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Mount Mitchell folio (No. 124), p. 2, 1905.
Bayley, W. S., Geology of the Tate quadrangle, Georgia: Georgia Geol. Survey Bull. 43, pp. 70-73, 140-141, 1928.

[26] Taber, Stephen, op. cit., pp. 128-129.

The gold belt of central Virginia lies in a zone of mineralization that extends across the State from north to south. Gold-bearing veins occur from the Potomac to and beyond Rappahannock River. Pyrite with some lead and zinc is abundant in Louisa County, and gold, pyrite, and copper occur in the area of the kyanite belt. Copper is found in the Virgilina volcanic area, which extends into North Carolina. Taber and others have stated that the ore-bearing veins show lack of crushing. If this is true they must be younger than the late Paleozoic movements and hence not related to the pre-Cambrian Columbia granite but to the Petersburg granite, which is widely exposed east and south of the kyanite belt. The Petersburg granite is undeformed and was intruded after the late Paleozoic thrust faulting, which metamorphosed the pre-Cambrian rocks in the zones of movement.

Kyanite in pegmatite in southwestern Virginia.—In the vicinity of Galax, in Carroll and Grayson counties, in southwestern Virginia, kyanite occurs in large blades and masses in pegmatite. These pegmatite bodies crop out parallel to each other along a strike about N. 50° E. They are west and south of Galax near State highway 12.

Two prospects, the J. C. Pierce and the Nuchols prospects, have been opened to a depth of several feet. The Pierce prospect lies north of west of Galax and highway 12 and the Nuchols prospect is south of that highway and separated from it by a hill. (See Fig. 1.) West of that hill on highway 12 and farther west on the Blair farm, kyanite in pegmatite crops out but has not been mined.

The pegmatites are composed of quartz, muscovite, and potash feldspar. In the Pierce prospect kyanite is in square broad blades. In the Nuchols prospect it occurs in thick aggregates of blue blades as much as 18 inches in length and extends out to the wall rock. (See Pl. 7.) Rutile is abundant in the pegmatite on the Pierce property and occurs in crystals weighing as much as a pound. Many crystals are multiple twinned. Mr. E. B. Crabill, of Galax, to whom the writer is indebted for help in locating the kyanite of this area, has collected such crystals known as sixlings or twins in which geniculation is six times repeated and produces a hexagonal prism surmounted by a six-sided pyramid with a reentering, six-sided hopper-shaped cavity at the top. Similarly twinned rutile crystals, namely, trillings, fourlings, sixlings, and eightlings, were reported by Shepard[27] and later described by many other mineralogists from Graves Mountain, Georgia.

The kyanite-bearing pegmatite is intrusive in the pre-Cambrian Lynchburg gneiss of the Galax area. The pegmatites are in general parallel to the foliation of the rocks but pinch out and swell and, to some extent, cut across the foliation. The mica gneiss in which they are intruded contains in places abundant garnet and

[27] Shepard, C. U., op. cit.

staurolite and scanty kyanite. Because the kyanite is developed in largest masses next to the mica gneiss of the wall rock, some of it may possibly have been formed from the leaching out of alumina from the mica gneiss by hot gases brought up with the pegmatitic material. A similar origin has been suggested for the kyanite in pegmatite of the Blue Ridge of North Carolina.

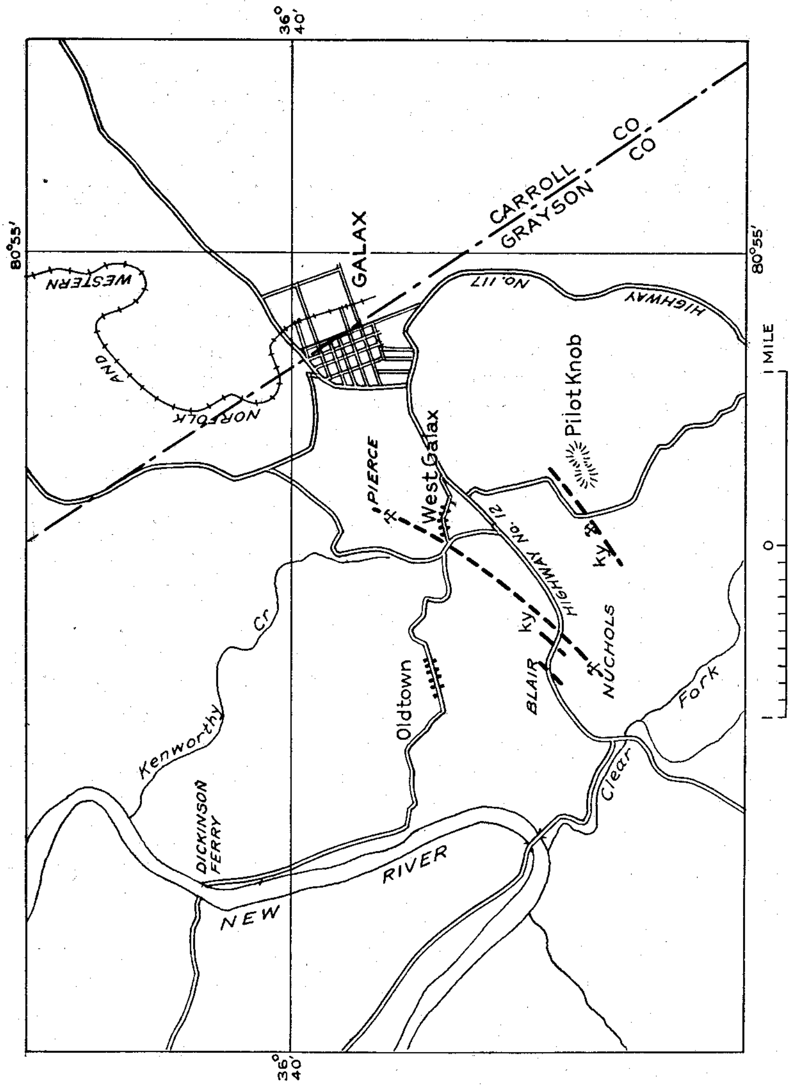
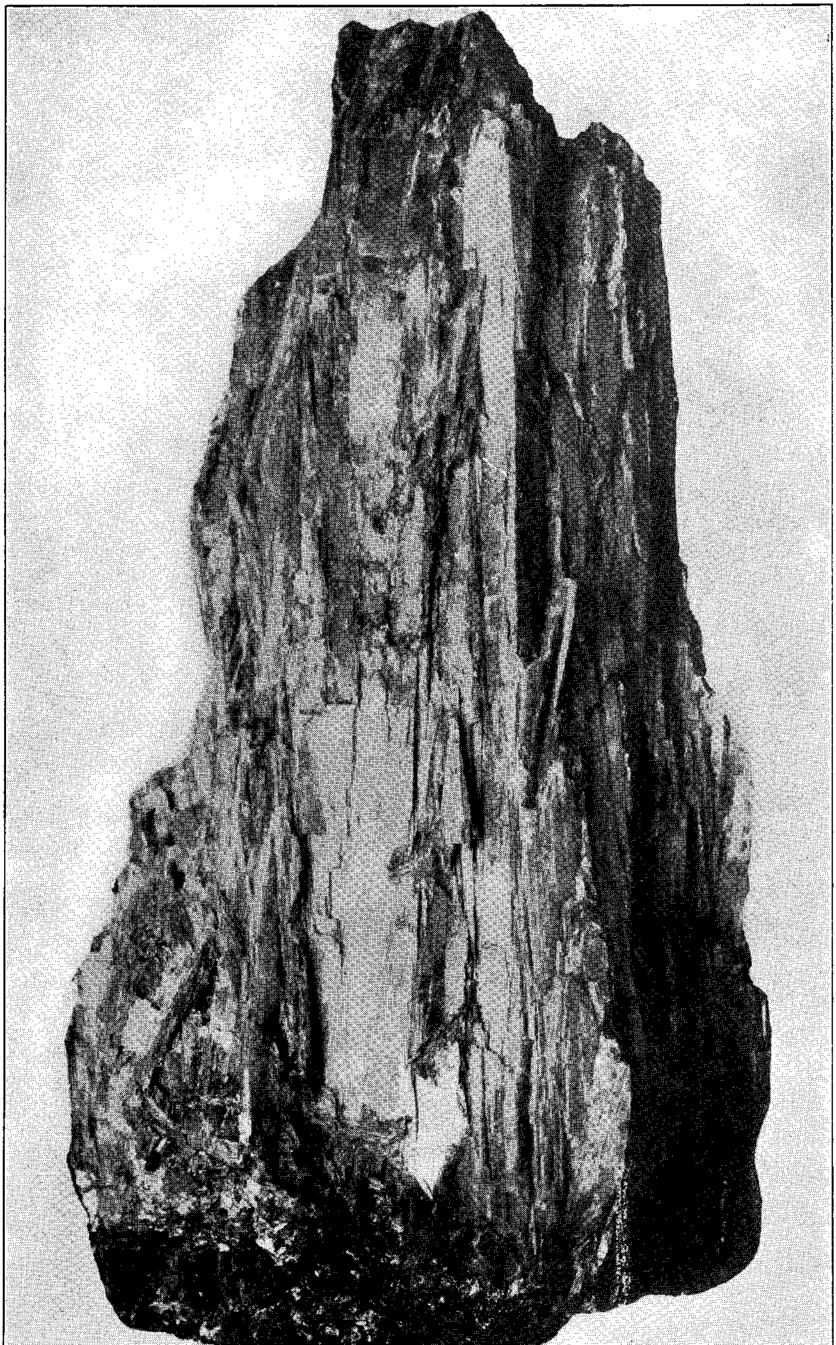
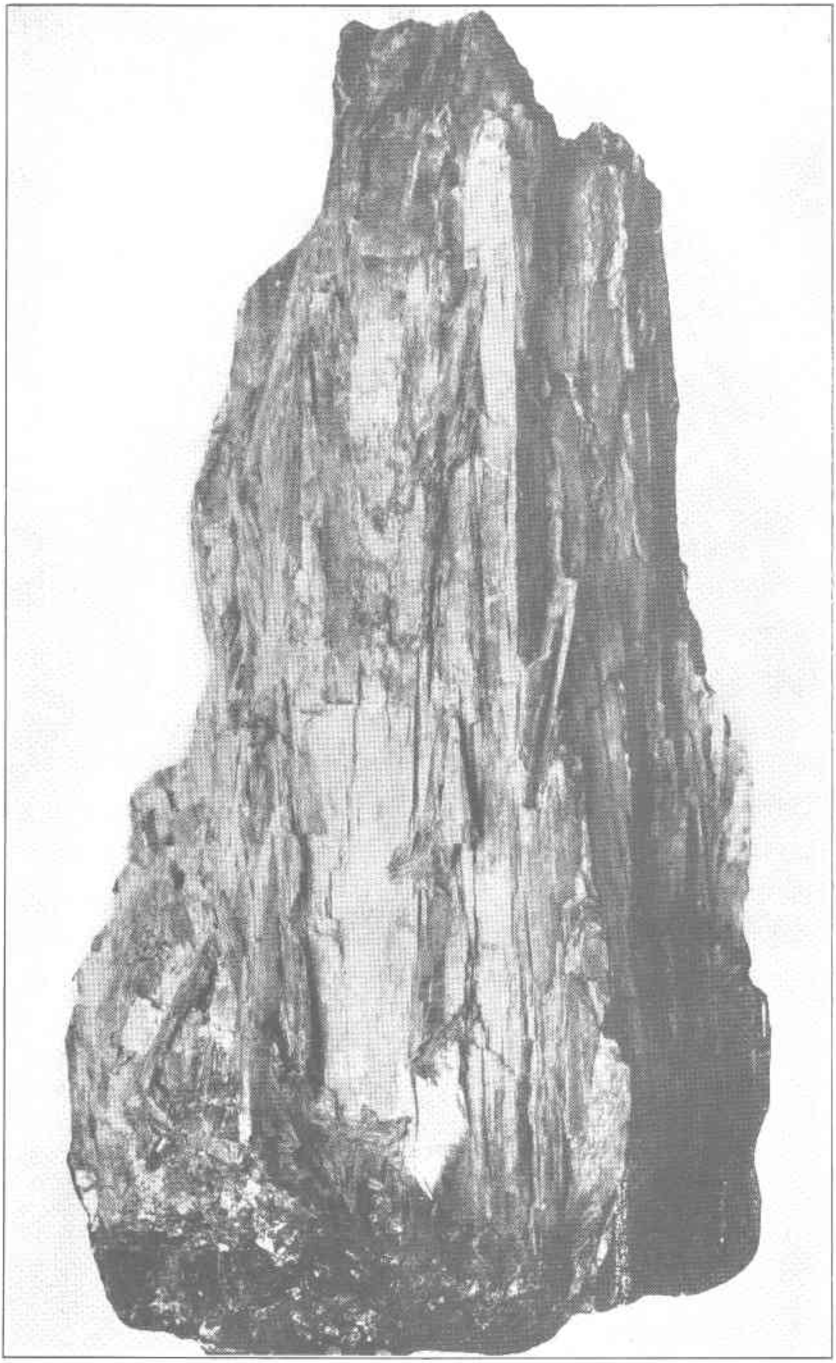


Figure 1.—Sketch map showing occurrence of kyanite-bearing pegmatite and kyanite prospects southwest of Galax. (From the topographic map of the Galax quadrangle.)



Massive kyanite in kyanite-bearing pegmatite at the Nuchols prospect southwest of Galax, in Carroll County. Rough lower edge was in contact with the country rock. Natural size.



Massive kyanite in kyanite-bearing pegmatite at the Nuchols prospect southwest of Galax, in Carroll County. Rough lower edge was in contact with the country rock. Natural size.

PRE-CAMBRIAN IGNEOUS ROCKS

HORNBLENDE GNEISS

The oldest pre-Cambrian intrusive rock in the kyanite belt is hornblende gneiss. The largest area of it lies west of Buckingham Courthouse, being 4 miles wide and extending about 12 miles along the strike, north of the area here mapped. It occurs also west and north of Burkeville, near Stony Point and Trenton Mills, 2 miles east of Columbia, near Wildway, Appomattox Courthouse, and west of Hat Creek.

Much of the hornblende gneiss occurs in narrow dikes or sills or forms an injection gneiss with the Wissahickon formation or the Columbia granite. Such relations have been represented on the map (Pl. 2) by a pattern over areas where Columbia granite contains much included hornblende gneiss.

LITHOLOGY

The hornblende gneiss of the eastern part of the kyanite belt is a black and white sparkling rock composed of hornblende with a satiny luster and white opaque feldspar, quartz, and epidote. The rock has a gneissic banding produced by the development of hornblende. The coarse-grained rock from the area west of Buckingham Courthouse is more massive and is composed of green hornblende and dull feldspar crystals. Where feldspar is removed by surface weathering, the rock has a pitted appearance. The feldspars have frayed edges and are dulled by alteration to albite, zoisite, epidote, and muscovite. The green hornblende is uralite containing cores of original unaltered hypersthene. Calcite, titanite altered to leucoxene, magnetite, apatite, and garnet are accessory minerals. The finer grained hornblende gneiss has the same mineral composition as the coarser but shows a more complete alteration to secondary minerals.

Southwest of Buckingham Courthouse through Appomattox Courthouse to Brookneal and northeast through Shores, Palmyra, and Kents Store the rock is fine grained and schistose. In hand specimens it is a gray-green schist with white streaks composed of quartz, albite, hornblende, chlorite, and epidote. The hornblende-epidote schist near Shores is intruded into chlorite-muscovite schist and quartzite of the Wissahickon formation. This injection rock has been quarried east of Shores. Similar schist occurs to the southwest near Eldridge Mill and southwest of Diana Mills and in fresh cuts near the point where highway 316 crosses Slate River. This hornblende schist has been called a basic volcanic rock, but no evidence of volcanic origin was found, and it resembles the fine-grained hornblende schist of intrusive origin found elsewhere in the area. Toward the southwest there is a similar fine-grained hornblende gneiss, and schist is interlayered with the chlorite-muscovite schist and the Shelton granite gneiss east of Appomattox Courthouse and from Andersonville to Brookneal. The origin of this hornblende gneiss is discussed below with that of the associated Shelton granite gneiss and granite mylonite.

ORIGIN

The minerals of the hornblende gneiss are largely secondary albite, epidote, and zoisite derived from a soda-lime feldspar, and uralite and chlorite derived from original pyroxene. It seems probable, therefore, that the original rock was a gabbro. That the magma was intruded in the form of sills can be seen from the concordant relations of the layering of the hornblende gneiss with the older schistosity of the Wissahickon formation, which is parallel to the original bedding. The hornblende gneiss has been closely folded since its intrusion, and its original minerals have been partly or wholly altered during the accompanying metamorphism.

COLUMBIA GRANITE

DEFINITION AND OCCURRENCE

The Columbia granite was named from its occurrence at Columbia,[28] on the Fluvanna-Goochland County line, north of James River. It has a wide distribution in the kyanite belt, in the eastern part of which it extends along the strike for a distance of 68 miles in an area 16 miles wide. The western edge of this large granite area lies 3 miles south of Palmyra, east of Bremo Bluff, Farmville, and Meherrin. Any included areas of Wissahickon schist and hornblende gneiss that are large enough have been mapped separately.

Another large area of granite extends from the southern edge of the area mapped northeastward through Prospect to Rosney and westward to Roland Hill and the region west of Terryville. It is divided into two areas north of Phenix, by a belt of the Wissahickon formation that extends southwestward through Madisonville and Elam.

Mylonitized granite, the Shelton granite gneiss facies of the Columbia granite, occurs in two zones. The eastern zone extends from a point north of Wilmington nearly to Rivanna River, and along the same strike to the southwest it extends from a point west of Cumberland through Farmville and east of Charlotte Courthouse. The western zone, mapped in part as Shelton granite gneiss on the geologic map of Virginia (1928), occurs in a belt 6 miles wide near Roanoke River and

[28] Taber, Stephen, Geology of the gold belt in the James River basin, Virginia: Virginia Geol. Survey Bull. 7, pp. 64-68, 1913.

extends northeastward to Andersonville in two areas separated by a narrow belt of Wissahickon muscovite-chlorite schist.

The freshest and largest exposures of the Columbia granite are found in the Cowherd quarries,[29] at Columbia, on the north side of James River, near highway 60. These quarries were last operated in 1900. Columbia granite crops out between Rice Depot and High Rocks in flat bosses in the fields near highway 60, where it was formerly quarried for building stone. There are fresh outcrops also near Whispering Creek and Willis River near highway 13, and in cuts near Cub Creek on a county road east of Red House (Pl. 5, B), in cuts of the Virginian Railway at Terryville, and near Nottoway River and Mallory Branch on highway 44. South of James River on highway 45 and near Cartersville on Muddy Creek there are many outcrops of Columbia granite. On the upland it disintegrates readily into a white sandy soil with few residual masses.

The Columbia granite is intrusive in the Wissahickon formation and the hornblende gneiss, and over large areas it forms a lit par lit injection with both of them. The resultant injection gneisses have been bent into closely recumbent folds overturned toward the northwest. Injection gneiss of this sort is exposed on State highway 60, west of Hampden Sidney, on highway 15 near Curdsville, on highway 20 west of Charlotte Courthouse, and on the Virginian Railway east of Falling River.

LITHOLOGY

The Columbia granite ranges in composition from quartz monzonite to granodiorite. The percentage of plagioclase (soda-lime feldspar) is notable and in some of the rock exceeds that of orthoclase. The rock is a gray biotite gneiss composed of quartz, feldspar, and biotite with small green epidote grains and pink garnets. It varies in the abundance and coarseness of the biotite crystals and is at some places porphyritic.

Thin sections show quartz, oligoclase, microcline, brown biotite with associated epidote, muscovite, and garnet and accessory titanite, ilmenite, calcite, zircon, and apatite. Ilmenite is altered to leucoxene. The micas are developed parallel to the gneissic banding; the quartz has undulatory extinction, and the potash feldspar is microcline as the result of pressure during crystallization of the granite. Epidote and calcite are secondary.

The Columbia granite near Columbia, Carysbrook, and Rosney has been described by Taber.[30] He mentions also a muscovite granite near Cartersville, but the granite exposed near the river at Cartersville and on Muddy Creek and southward contains biotite as well as muscovite.

[29] Watson, T. L., Granites of the southeastern Atlantic States: U. S. Geol. Survey Bull. 426, pp. 112-113, 1910.
Taber, Stephen, op. cit.

[30] Taber, Stephen, op. cit., pp. 62-82.

SHELTON GRANITE GNEISS FACIES

A mylonitized facies of the Columbia granite called the Shelton granite gneiss occurs in two zones. It is represented on the map (Pl. 2) by a pattern printed over that of the Columbia granite.

Eastern zone.—The best exposures of the eastern zone occur on highway 13 east of Ca Ira, in the cuts of the Virginian and Norfolk & Western railways where highway 15 crosses them, in southern Charlotte County near Saxe and Randolph south of the area mapped, and near Meherrin River at Double Bridges. The granite gneiss of this zone is a fine-grained rock that lies in close folds overturned to the northwest. Southeastward-dipping cleavage obscures the folds except where bands of hornblende gneiss into which the granite is injected bring out the lamination. Such a folded injection gneiss is well exposed on highway 13 east of Rock Creek, east of Farmville, and in cuts of the Virginian Railway.

The granite gneiss is a cream-colored to pink fine-grained gneiss with drawn out feldspar augen and fine-grained schistose layers. The hand specimen shows quartz, feldspar, fine biotite, and muscovite; epidote is also present, especially near hornblende bands. In thin section the feldspar is seen to be cracked and granulated on the edges and altered to sericite; both plagioclase and microcline occur. A very cataclastic specimen from the cut of the Virginian Railway where highway 15 crosses it, shows feldspar clouded with epidote, biotite sliced and bleached and altered to epidote, and garnets broken into small grains. The rock is almost completely microgranulated with few porphyroclasts and is a mylonite or mylonite schist.[31]

Fine-grained augen gneiss and granite mylonite occur east of Palmyra from Wilmington to Kents Store. They are closely folded and contain many thin layers of fine-grained hornblende gneiss. This zone of fine-grained rock extends nearly to Rivanna River, where it passes southward into coarser grained, less deformed Columbia granite.

Western zone.—The western zone of granite gneiss, augen gneiss, and granite mylonite lies west of the area of Columbia granite whose western edge passes through Roland Hill and west of Terryville. The boundary between the two facies is exposed in cuts on the Virginian Railway east of Falling River. The Columbia granite in the eastern cut is a fine-grained biotite granite gneiss interlayered with hornblende gneiss; in the next cut to the west is exposed a more schistose muscovite-biotite granite gneiss of the type called Shelton granite gneiss. This area of granite gneiss and augen gneiss extends west of the mouth of Falling River through Brookneal and westward, and fresh cuts along the Virginian Railway expose an almost continuous section across it.

[31] Lapworth, Charles, The highland controversy in British geology: Nature, vol. 32, pp. 558-559, 1895.

Outcrops on the county road that crosses Falling River 3 miles north of Brookneal furnish a partial section. This granite gneiss extends northeastward 34 miles to Andersonville in two areas separated by a narrow belt of Wissahickon mica schist which crosses Roanoke River 2 miles west of Brookneal. Cuts along Appomattox River and Rough and Cub creeks afford exposures of the granite gneiss in the northern part of the area. This zone of granite gneiss and augen gneiss is the north end of a belt that extends southwestward into central North Carolina through Danville, Va., and into North Carolina near Shelton, where it is quarried and from which its name was taken. South of Shelton it extends through Winston-Salem to Mocksville, N. C.

The granite gneiss of the area extending from a point just east of the bridge of the Virginian Railway over Falling River to a point 3 miles west of Brookneal is a very cataclastic gray and white schistose gneiss composed of quartz, feldspar, muscovite, biotite, epidote, and garnet. This granite gneiss is closely folded, and the folds are overturned to the northwest. The micas form a prominent banding, and on weathering the gneiss breaks into pencils like slivers of quartz and feldspar wrapped with mica. (See Pl. 8.)

Thin sections show that the larger feldspars, microcline and oligoclase, are frayed on the edges and cracked into fragments. Garnet also is broken. The banding of the rock is formed by mica and epidote, which occur in bands in a fine matrix of quartz and microcline. Part of the mica is bleached biotite, of which there are brown remnants. The greater part is pale-green muscovite, which occurs in fresh blades formed by neomineralization during cataclasis of the granite. The rock is an augen schist.

West of Brookneal there occurs much coarse augen gneiss with pink feldspars cracked and drawn into lenticles in a fine quartz-feldspar matrix. The augen are formed of microcline and oligoclase, broken on the periphery, with finely granulated bands across them. They are altered to sericite and epidote and are dusted with fine iron particles. The groundmass is made up of quartz and feldspar formed by granulation. The biotite is broken and altered to epidote and chlorite, which in places contain inclusions of zircon with pleochroic haloes. The augen gneiss has been formed by the crushing of a coarser grained granite accompanied by a subordinate amount of neomineralization.

Granite mylonite.—West of Brookneal the augen gneiss contains fine-grained layers that resemble a felsite or a quartzite. The rock is straight layered and light colored, contains grains of quartz and feldspar that are barely discernible with a hand lens, and shows micaceous partings. In thin section these fine-grained bands prove to be granite mylonite in which crushing of the constituents has been much greater than in the augen gneiss. The quartz and feldspar are finely granulated, with few remnants of larger feldspars not entirely rolled out to the size of the grains in the matrix. Biotite is bleached and broken, and epidote is in very fine grains. The scanty muscovite that occurs along the bands is developed from potash feldspar by neomineralization during mylonitization. These straight-layered felsitic rocks represent zones in the granite gneiss in which ultracataclasis took place with some neomineralization.

The fine-grained hornblende gneiss that is intercalated with them shows evidence of a similar origin. Feldspar occurs in porphyroclastic eyes granulated and almost completely altered to epidote, zoisite, and calcite. The bulk of the rock is made up of fine laths of green hornblende and chlorite showing parallel orientation, with fine interstitial quartz and feldspar. The feldspar eyes alone show the cataclastic history of the rock. The hornblende, chlorite, and interstitial quartz and feldspar are products of neomineralization during mashing.

In the areas of granite gneiss northeast of Brookneal coarse-grained augen gneiss is exposed near Morris Church and east of Falling River near the road to Red House. Farther northeast the granite gneiss contains many fine-grained layers with little coarse augen gneiss. This fine-grained granite gneiss and granite mylonite weather to a crumbly micaceous sand like that derived from quartzose beds of the Wissahickon formation. Because of lack of fresh outcrops it is probable that some granite mylonite has been included in the areas mapped as the Wissahickon formation.

MELROSE GRANITE FACIES

Distribution and character.—The augen gneiss zone extends west of Brookneal to McKeever Ferry, and the augen gneiss of the western part of it is derived from the Melrose granite lying west of McKeever Ferry. The Melrose granite forms an area 2 miles wide and about 10 miles long. A mile east of Melrose station it is covered by Triassic sediments. It is much coarser grained and darker colored than the Columbia granite. It contains coarse pink phenocrysts of feldspar, green biotite, and blue quartz. Under the microscope the feldspars are seen to be microcline and oligoclase altered to epidote, zoisite, and sericite and dusted by fine iron, to which their pink color is due. The biotite is in coarse green blades associated with abundant titanite and apatite. Some of the titanite is altered to leucoxene. The blue color of the quartz is due to inclusions of rutile needles. The somewhat shattered condition of the feldspar phenocrysts shows that the rock has suffered cataclasis. (See Pl. 9, B.)

In the area east of McKeever Ferry the Melrose granite has been converted into an augen gneiss. This zone is 1½ miles wide and on the east merges into the augen gneiss derived from the Columbia granite.

The augen gneiss derived from the Melrose granite contains pink feldspar (porphyroclasts) in a dark-colored schistose matrix of fine muscovite and abundant epidote and chlorite derived from biotite. The large feldspars are much broken and elongated into eyes, and the dark constituents are arranged in layers that wrap around them.

On Whipping Creek, 3 miles northeast of Melrose, there is a dark layered schist containing knots and stringers of pink feldspar. This rock is in a more advanced stage of mylonitization than the augen gneiss just described. The feldspars have been reduced to angular grains cemented by calcite. The rock is much stained by hematite.

AGE

The Columbia granite is intrusive in the Wissahickon formation and the hornblende gneiss. At Carysbrook it is overlain unconformably[32] by the Arvonia slate, of late Ordovician age. The Columbia granite is therefore pre-Ordovician. Because it intrudes only pre-Cambrian rocks there is no direct proof that it may not be Cambrian. There is, however, no evidence of Cambrian diastrophism nor of widespread Cambrian igneous intrusion in the Cambrian rocks of the southern Appalachian region; hence it is probable that the Columbia granite is pre-Cambrian. It has been shown that in two zones the Columbia granite has been much deformed and changed into augen gneiss and granite mylonite whose original composition was the same as that of the granite. This change was produced by granulation of the constituents accompanied by more or less neomineralization. The formations associated with the granite in the crushed zones were also reduced in grain. The biotite-muscovite Wissahickon schist is changed to a finer grained chlorite-muscovite schist, and the mesozone minerals changed to those typomorphic of the epizone. The mylonitization of granite and the diaphthoresis and reduction in grain of the Wissahickon were greatest in the area east of Appomattox Courthouse, near the edge of the Appomattox overthrust, whose age is considered to be late Paleozoic.

MUSCOVITE PEGMATITE

Muscovite pegmatite intrudes the Wissahickon formation, hornblende gneiss, and Columbia granite in narrow crosscutting dikes. It has been mapped where it was found most abundantly. It cuts the Columbia granite west of Phenix, Rough Creek and Madisonville, north and south of Prospect, and northwest of Baker Mountain. It is abundant in the Columbia granite north of Elk Hill along Byrd Creek. Near Appomattox River at Clementon Mills it intrudes hornblende gneiss. It occurs in the Wissahickon formation north of Jetersville

[32] Taber, Stephen, op. cit., p. 41. See also Pl. 6, fig. 1.

and in exposures in the Columbia granite on Little Nottoway River and Modesty Creek south of Burkeville. It is a coarse-grained pegmatite composed of orthoclase, quartz, and muscovite containing garnet in places. It probably represents a late phase of the Columbia granite intrusion.

VIRGILINA VOLCANIC ROCKS

Acidic and basic volcanic rocks occur in a small area between Meherrin and Keysville. This area is included in the map of the Virgilina district,[33] and the report on that district describes these rocks in detail. They are poorly exposed in the kyanite belt. The best outcrops of the basic volcanic rocks occur on Meherrin River near Double Bridges and on highway 501 east of Meherrin. The acidic volcanic slate crops out west of Keysville. On the northern borders the volcanic rocks underlie an upland with few exposures, and the northern boundary has been dotted on the map. They extend southwest 35 miles to Virgilina, on the Virginia line, and across North Carolina into South Carolina.

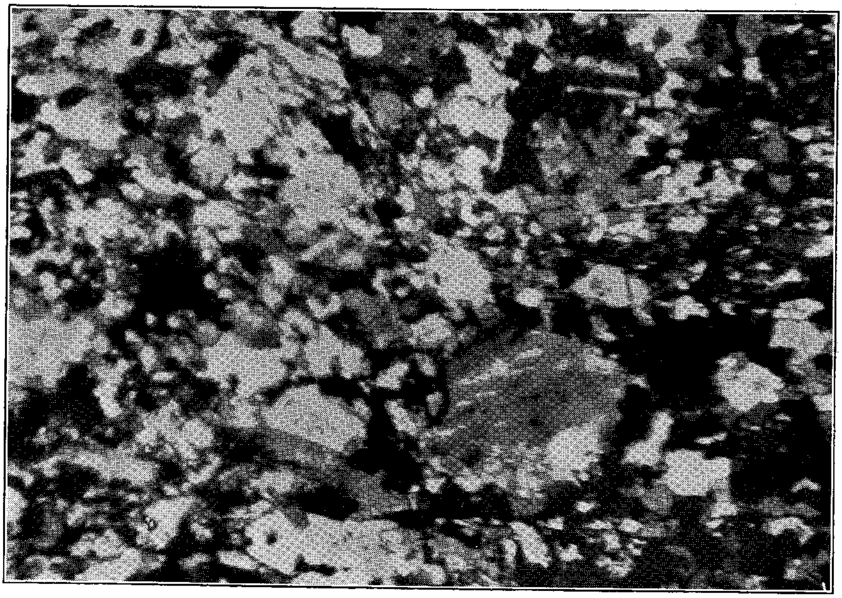
Basic volcanic rocks.—The basic facies is a greenstone schist derived from andesitic flows and tuff. Farther south there are porphyritic and amygdaloidal types.[34] The schist is a grayish-green rock composed of plagioclase, hornblende, chlorite, epidote, zoisite, calcite, apatite, the black ores, and quartz. The hornblende, chlorite, epidote, and calcite are secondary minerals. The zoisite is an alteration product of the feldspar.

Acidic volcanic rocks.—The acidic facies is a sericite-quartz schist derived from a rhyolite or rhyolite tuff. In the area west of Keysville it has been called Aaron slate.[35] It weathers to a soft crumbly schist. Three miles southeast of Double Bridges on highway 48, just south of the area here mapped, there is an area of vitreous aporhyolite.

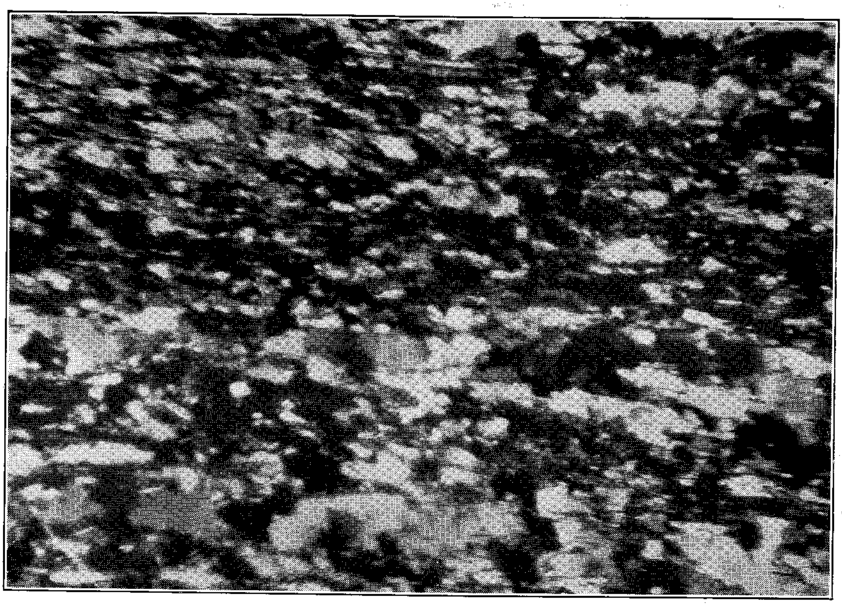
Age.—The Virgilina volcanic rocks are older than the Columbia granite, which intrudes them at Double Bridges and elsewhere, and are of pre-Cambrian age. They have not been seen in contact with the Wissahickon formation, but because of their position on the downfaulted side of the Triassic areas east of Charlotte Courthouse and Scottsburg it is probable that they overlie the Wissahickon, which occurs on the uplifted side west of the normal faults.

In the region east of Lynchburg basic volcanic rocks occur under the Mount Athos quartzite[36] and are the oldest rocks exposed in that area. The Mount Athos quartzite, which may be the equivalent of the Setters quartzite, underlies marble that is probably the equivalent of the

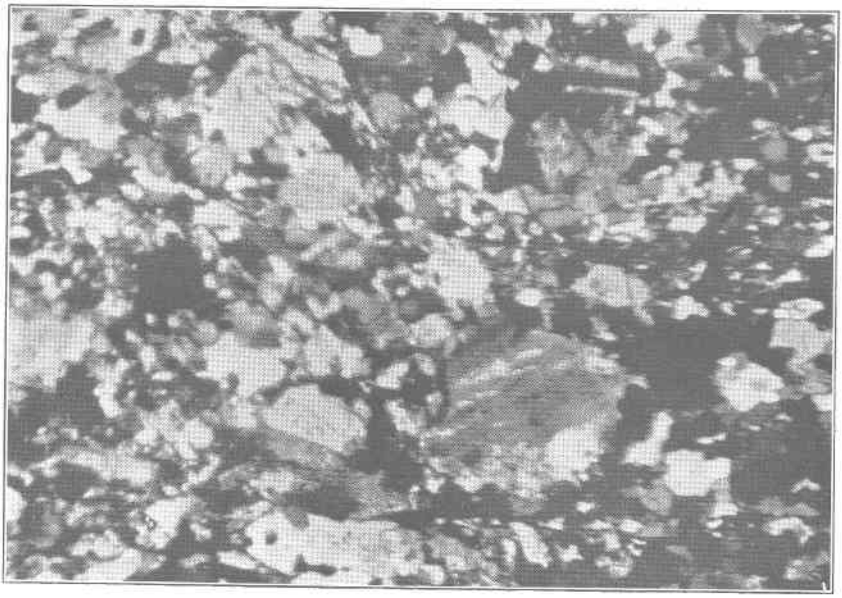
[33] Laney, F. B., The geology and ore deposits of the Virgilina district of Virginia and North Carolina: Virginia Geol. Survey Bull. 14, 1917.
[34] Laney, F. B., op. cit., pp. 19, 27-34.
[35] Idem., pp. 19, 24-27.
[36] Furcron, A. S., James River iron and marble belt, Virginia: Manuscript in the files of the Virginia Geol. Survey.



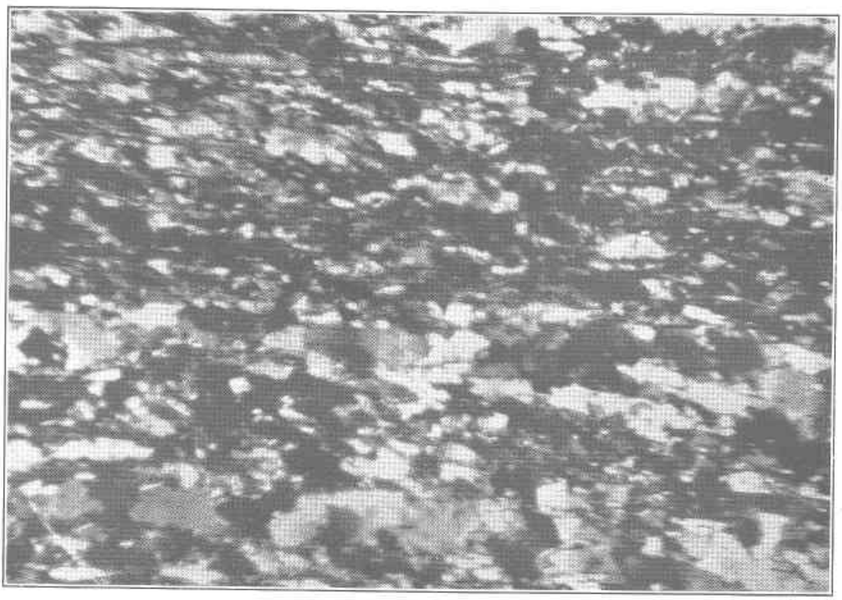
A. Shelton granite gneiss facies, an augen gneiss from Falling River north of Brookneal. Shows cataclastic texture. Plain polarized light, crossed nicols; X 38.



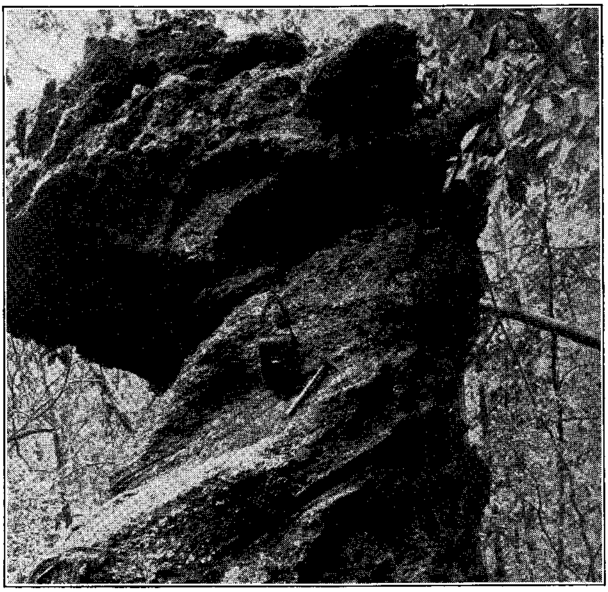
B. Mylonitized granite from Falling River north of Brookneal, Campbell County. Shows combination of cataclastic texture and neomineralization. Plain polarized light, crossed nicols; X 38.



A. Shelton granite gneiss facies, an augen gneiss from Falling River north of Brookneal. Shows cataclastic texture. Plain polarized light, crossed nicols; X 38.

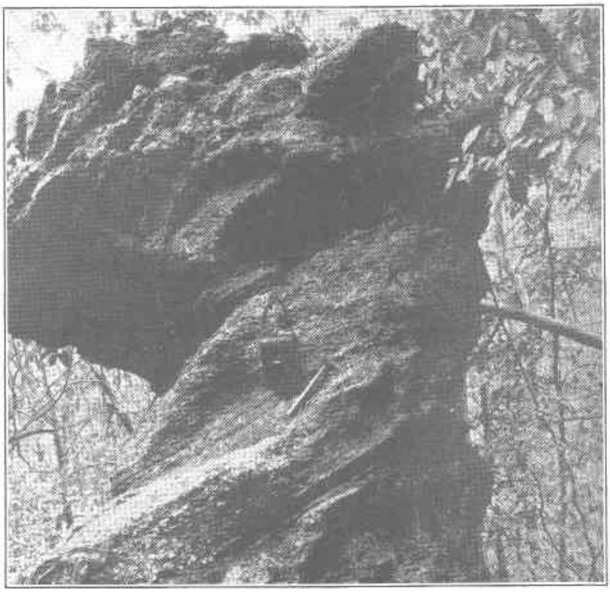


B. Mylonitized granite from Falling River north of Brookneal, Campbell County. Shows combination of cataclastic texture and neomineralization. Plain polarized light, crossed nicols; X 38.

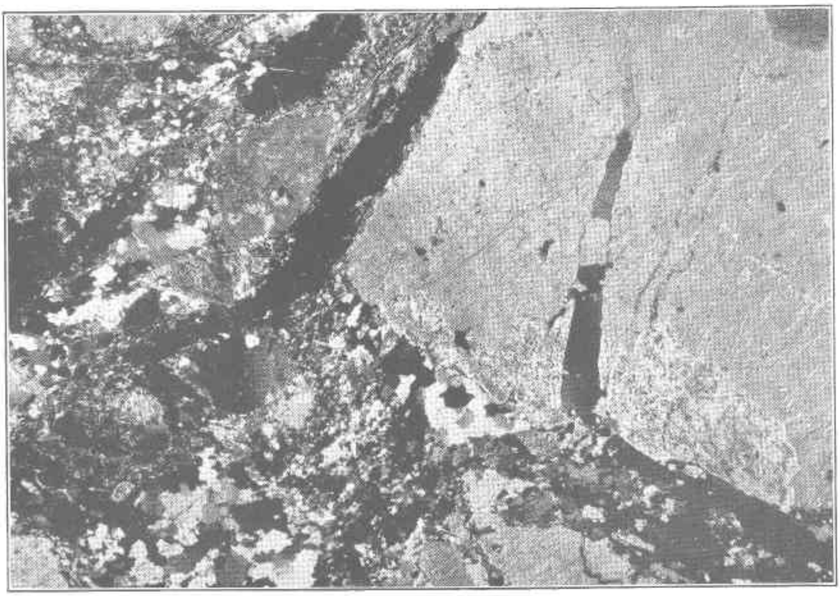


A. Weathered kyanite-bearing rock on Ridge Mountain, Buckingham County.

8. Melrose granite, east of McKeever Ferry, on Roanoke River. Cataclastic groundmass of quartz and feldspar with a feldspar phenocryst somewhat fractured. Plain polarized light, crossed nicols; X 9.



A. Weathered kyanite-bearing rock on Ridge Mountain, Buckingham County.



8. Melrose granite, east of McKeever Ferry, on Roanoke River. Cataclastic groundmass of quartz and feldspar with a feldspar phenocryst somewhat fractured. Plain polarized light, crossed nicols; X 9.

Cockeysville marble. Basic volcanic rocks occur also at a higher horizon in or above the Wissahickon formation, which overlies the Cockeysville marble in that area, and these rocks may be at the same horizon as those of the Virgilina belt.

ORDOVICIAN ROCKS

ARVONIA SLATE

General features.—The slate belt near Arvonia was described by Rogers[37] as early as 1835, and he referred to its excellence as a roofing slate. Watson[38] describes the Arvonia slate and gives a list of references to literature on the subject. It is best exposed on James and Slate rivers, and in the quarries at Arvonia, where it strikes N. 20°-30° E. and the cleavage dips 70°-80° SE. It is closely folded.

The slate rests on Columbia granite near Carysbrook, but elsewhere it overlies the Wissahickon formation and intruded hornblende gneiss.

It is a dark-gray to black lustrous slate, exceedingly tough and nonfading. Some beds are graphitic; others are pyritiferous and contain thin sandstone layers at places near the base and higher in the section. The microscope shows a distinctly crystalline texture in the slate approaching that of the phyllitic stage of metamorphism. Its constituents are sericite, quartz, and chlorite, with accessory tourmaline and zircon.

Quarries.—Active quarries in the slate center around Arvonia. The only quarry north of James River was on the western edge of the area, west of the Colonial estate Bremo. Many stone walls and foundations and roofs of the older buildings of the region are made of the slate. The quarries at Arvonia have been in active operation for a long time and furnish a high-grade nonfading roofing slate.[39]

Age.—Fossils have been found in the Arvonia slate by Darton[40] and others in an old quarry east of Arvonia station. They include crinoids, brachiopods, and trilobites of late Ordovician (Maysville) age.[41] Slate of the same age occurs near Quantico and Dumfries, in northeastern Virginia.[42] The Arvonia slate is similar in character also to the Peach Bottom slate of Maryland and Pennsylvania, whose age is not known because no fossils have been found in it.

The Ordovician slates of Virginia occur in closely folded synclines overturned to the northwest. They overlie unconformably the pre-

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[37] Rogers, W. B., A reprint of annual reports and other papers on the geology of the Virginias, pp. 78-79, New York, D. Appleton and Co., 1884.

[38] Watson, T. L., Mineral resources of Virginia, Virginia-Jamestown Exposition Commission, pp. 41-47, 52, 1907.

[39] A detailed study of this slate has been made recently by J. D. Burfoot, Jr., for the Virginia Geological Survey.

[40] Darton, N. H., Fossils in the "Archean" rocks of central Piedmont, Virginia: Am. Jour. Sci., 3d ser., vol. 44, pp. 50-52, 1892.

Watson, T. L., and Powell, S. L., Fossil evidence of the age of the Virginia Piedmont slates: Am. Jour. Sci., 4th ser., vol. 31, pp. 33-44, 1911.

[41] Personal communication from Charles Schuchert and R. S. Bassler.

[42] Watson, T. L. and Powell, S. L., op. cit.

Cambrian rocks and represent the only remnants of Paleozoic deposits preserved on the Martic thrust block. In southern Pennsylvania and Maryland Lower Cambrian arenaceous sediments overlie pre-Cambrian rocks of this overthrust block in the Sugar Loaf syncline, but if Lower Cambrian sediments were deposited in the adjoining area in Virginia they were removed before the late Ordovician deposition.

During the late Paleozoic orogeny the Arvonia slate was folded and metamorphosed to the stage of a phyllite. While the slate was undergoing progressive metamorphism under epizone conditions the pre-Cambrian mesozone schists (Wissahickon) on which it lies suffered retrogressive metamorphism and the development of a second foliation parallel to that developed in the slate.

TRIASSIC ROCKS

SEDIMENTARY ROCKS

AREAS IN KYANITE BELT

Distribution.—Triassic sediments in the eastern United States occur in several separate areas and the beds in these areas dip northwest and southeast away from the Triassic anticlinal axis. (See Pl. 1.) The Triassic sediments of the kyanite belt lie on the west side of the axis midway between the large Triassic belt of the western border that extends from New Jersey to central Virginia, and the Richmond basin.

The areas in the kyanite belt occur along parallel zones trending N. 30° E. and 16 miles apart across the strike. The western area is 20 miles east of the Scottsville, Va., area, which is in strike with the large New Jersey-Virginia basin. The eastern areas are 30 miles west of the Richmond basin.

There are four small areas along the eastern zone, which extend north of Ca Ira and south of Charlotte Courthouse. The most southerly area extends from a point 3 miles south of Abilene to a point 3 miles southwest of the area shown on the accompanying geologic map. (See Pl. 2.) The largest area along the eastern zone is 15 miles long and 5 miles wide at its south end. It extends from a point 3 miles north of Ca Ira, on the west side of the Cumberland-Farmville highway, to Appomattox River north of Farmville. Its western edge is 1 mile east of Curdsville and Sheppard. Outcrops occur on the old plank road that runs north from Farmville across Willis River, on a county road northwest from Fork Store, and on highway 13 west of Ca Ira. The two areas south of Farmville are small, being only 3 to 5 miles long and slightly more than 1 mile wide.

The western area of Triassic sediments is the northeast end of the Dan River area and extends southwest from a point near Spring Mills into North Carolina.

Character.—The Triassic sediments of all these areas unconformably overlie the crystalline rocks and dip 20°-30° NW. They are composed of pebbly red micaceous and arkosic sandstone at the base, with overlying olive-yellow arkosic sandstone and interbedded yellow shale and red sandstone. The Farmville area contains more shale than the others. The beds in all the areas dip west and are cut off on the west side by normal faults. The beds in the Farmville area end sharply across the strike along a line parallel to Appomattox River, and this abrupt termination may be the result of a cross fault. On the western margin of the Farmville area there is a band of coarse conglomerate half a mile wide. It is made up of large blocks of granite gneiss and hornblende gneiss in a red sandy matrix derived from a near-by source. Where exposures were observed in the narrow area of Triassic rocks east of Charlotte Courthouse all the material was a similar conglomerate.

In the Dan River area a thin conglomerate occurs on the western margin east of Tweedy Creek, on the road from Red House to Rustburg. This conglomerate resembles a fault breccia composed of fragments of chlorite-muscovite schist derived from the schist west of these Triassic beds.

Fossils that are characteristic of the westerly belt of Triassic rocks in general have been found in the Dan River and Farmville areas. They comprise fossil trails, conifer stems, and fragments of petrified tree trunks and in the Farmville area plants in black carbonaceous shale similar to those found in the Richmond basin.[43] Coal was mined to a small extent 1 mile northwest of Farmville before 1900. The finding of coal and similar coal plants in the Farmville and Richmond basins points to a possible connection of these two areas in Triassic time.

In the large New Jersey-Virginia basin, with which the Scottsville area is in strike, the Triassic sediments are divided into two formations —a lower one composed of purple to gray arkosic sandstone with red sandstone beds and a coarse conglomerate bed at its base and an upper one made up of red shale and red sandstone. They have been named the New Oxford[44] sandstone and Gettysburg shale in southwestern Pennsylvania and Maryland and the Manassas sandstone and Bull Run shale in Virginia.[45] Only a small thickness of these beds remains in the Triassic areas in the kyanite belt. They are made up of arkosic yellow and red sandstones with a pebbly conglomerate at the base lithologically similar to the New Oxford formation of the main basin, and they were deposited under similar conditions of sedimentation from

[43] Roberts, J. K., The geology of the Virginia Triassic: Virginia Geol. Survey Bull. 29, pp. 143-149, 1928.

[44] Jonas, A. I., and Stose, G. W., Geology and mineral resources of the New Holland quadrangle, Pennsylvania: Pennsylvania Geol. Survey, 4th ser., Top. and Geol. Atlas of Pennsylvania No. 178, pp. 16-17, 1926.

Stose, G. W., U. S. Geol. Survey Geol. Atlas, Fairfield-Gettysburg folio (No. 225), pp. 8-10, 1929.

[45] Roberts, J. K., op. cit., pp. 24-38.

an uplifted land mass to the east composed of weathered crystalline rocks.

In the New Jersey-Virginia basin, where a fuller sequence of beds is preserved and there is better opportunity to study the formation of the basin and the conditions of deposition, it has been concluded by the writer and other workers[46] that the sediments were deposited in a long, narrow basin that deepened progressively northwestward, the first deposits being laid down only in the southeastern part and later deposits spreading progressively farther westward. The sediments were derived from a highland to the east and were swept into a basin that gradually deepened by progressive subsidence on the west side. Only a small part of the total thickness of sediments should therefore be found at any one place.

FANGLOMERATE

The main Triassic area which extends from New Jersey to central Virginia is bounded on its northwest side by normal faults, which uplifted the block northwest and west of it. The faulting began before the end of Triassic deposition, and where upward movement was rapid a fanglomerate was formed on the west side of the basin, made up of rounded and angular blocks derived from the adjoining western highland and not from the east side of the basin. The material of which the fanglomerate is composed therefore indicates what were the formations that were exposed in the highland northwest and west of the Triassic basin shortly before deposition ceased. In southern Pennsylvania, Maryland, and northern Virginia[47] the fanglomerate is composed of Paleozoic limestone. This limestone also forms the floor on which sediments were deposited near the western border fault. Since Triassic time these limestones have been entirely removed from the area west of the fault where basal Cambrian and pre-Cambrian rocks are now exposed. The limestone floor has been dropped an amount equal at least to the thickness of the underlying Cambrian siliceous rocks plus the height of the present mountains above the level at their eastern foot, probably more than 6,000 feet.

South of Rappahannock River the Triassic rocks are bordered on the west by a fanglomerate made up of Catoctin metabasalt blocks derived from the near-by highlands, which were here composed of metabasalt instead of Paleozoic limestone, as farther north. Southwest of Rapidan to a point south of Gordonsville, the Triassic occupies a fault trough down dropped in the Catoctin metabasalt.

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[46] Stose, G. W., Idem, p. 9, 1929.
Wherry, E. T., North border relations of the Triassic in Pennsylvania: Acad. Nat. Sci. Phila. Proc., vol. 65, pp. 118-24, 1913.

[47] Stose, G. W., op. cit., p. 10.
Roberts, J. K., op. cit., pp. 10-13.
McLaughlin, D. B., Michigan Acad. Sci., Arts and Letters, vol. 16, pp. 425-427, 1932.

The Scottsville area which lies along the same strike 25 miles southwest of Barboursville, forms the southwest end of the Triassic rocks along this strike. It contains on its west side a fanglomerate of Catoctin metabasalt similar to that of the main part of the westerly belt, to the northeast.

CONDITIONS OF DEPOSITION

The question arises whether the Triassic beds of the Dan River, Farmville, and Richmond areas were deposited as part of this main westerly basin and were separated from it by normal faulting and subsequent erosion, or whether they were deposited in narrow disconnected basins. The similar lithologic character of the sediments in all the basins indicates a similar source and similar conditions of sedimentation. Only the westernmost basin contains the upper Triassic beds of Gettysburg shale and the western border fanglomerate, which indicates that the Dan River and Farmville areas represent remnants of a wider basin of sedimentation now separated from the main belt to the west by an upfaulted area of crystalline rocks from which the Triassic cover has been removed. The distance from the eastern edge of the Richmond basin to the western border fault is about 60 miles, only 10 miles wider than the width of the Triassic belt in part of eastern Pennsylvania, and a continuous basin of that width may have been present in Virginia as well as in Pennsylvania.

SOURCE OF SEDIMENTS

The source of the sediments of the westerly belt of Triassic, except for the last (fanglomerate) phase, lay to the east. The highland that supplied the material lay east of the Farmville area, or, if that area were continuous with the Richmond basin, it lay east of the Richmond basin. Roberts[48] explains the development of thick fanglomerate on the western border of the basin as being due to greater height of the highlands west of the Triassic areas, because these highlands were a part of the Appalachian Mountains formed during Permian time. The Blue Ridge now west of the Triassic area consists of residual mountains of differential erosion of an old peneplain. The folded Appalachian Mountains formed by late Paleozoic orogeny extended from the region east of the Richmond basin westward across the present folded and faulted tract of the Piedmont and Blue Ridge crystalline rocks and the folded Paleozoic rocks farther west. The area of the Martic thrust block, as well as that of the Catoctin-Blue Ridge anticlinorium west of it, was folded and broken by thrust faults and represents the inner or eastern part of the folded Permian mountain range.

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[48] Roberts, J. K., op. cit., p. 156.

The Petersburg granite east of the Richmond basin was at the surface when the Triassic sediments were deposited. It was intruded into the Permian mountain range in late Paleozoic time, and its texture indicates that it must have consolidated under a cover at least 2,000 and perhaps 4,000 feet thick.[49] As this cover and part of the underlying granite were eroded between the time of its consolidation and the late Triassic sedimentation, it affords a rough measure of the depth to which the Permian mountains were eroded before late Triassic time.

The Triassic basins were produced by tension faulting of the highland surface formed by erosion of the Permian mountains. Faulting continued during sedimentation and brought it to an end. Block mountains formed by vertical uplift took the place of the folded Appalachian Mountains, which had been eroded to their roots in the inner part of the range before Triassic sedimentation began. These block mountains were peneplained in post-Triassic time. This peneplain was arched in Tertiary time and is now preserved in remnants on the crest of the Blue Ridge.

DIABASE

The rocks of the kyanite belt are cut by many dikes of diabase, which are for the most part less than 40 feet in width. In general they range in strike from about N. 25° E. to N. 20° W. They are most numerous in the strike of the Farmville Triassic area, where they occur in parallel lines about 1 to 3 miles apart. The longest distance any dike has been traced along the strike is 25 miles. Diabase crops out for the most part in highway, railroad, and stream cuts and is exposed in place on highway 15 south of Cunningham Creek. The same dikes crop out on highway 19 east of Columbia and to the northeast and west of Byrd Creek. Other outcrops occur on highway 13 west of Willis River, on highway 15 at the crossing of Willis River, and north of Appomattox River at Stony Point Mills and on highway 15 near Worsham. The dike that passes through Cullen crops out in the cut of the Norfolk and Western Railway east of Madisonville and on Little Roanoke Creek at the crossing of highway 304. Diabase weathers to rounded masses by exfoliation of thin surficial layers, and except where it was found in place it is mapped by the trail of boulders lying on the surface.

Where diabase is intruded in the Triassic sediments it has hardened them and changed their color from red to blue-black by reduction of the iron oxide. It has had no metamorphic effect on the crystalline pre-Cambrian rocks it intruded. Contacts of the dikes and country rock are vertical to slightly inclined. In thin section the diabase is seen to be made up of acidic labradorite and green augite with a diabasic or

[49] Smith, W. S., Stratigraphy of the Skykomish Basin, Washington: Jour. Geology, vol. 24, p. 561, 1916.

ophitic texture. Accessory minerals are magnetite, apatite, quartz, biotite, and orthoclase.

The diabase of the dike that passes through Cullen has been called hornblende syenite.[50] It extends from a point east of Pamplin southeastward and lies west of Baker Mountain, east of Charlotte Courthouse. At Drakes Branch, a station on the Southern Railway south of the area here mapped, it is more than 150 feet wide.[51] It is a gray to pink and medium- to coarse-grained diabase with twinned automorphic feldspars and green to brown augite that crystallized later than the feldspar. The augite is altered to hornblende, and the feldspar to muscovite. Such alteration is not usual in Triassic diabase, but because the Cullen dike cuts Triassic sediments of the area east of Charlotte Courthouse its Triassic age is established. The other diabase dikes cut Triassic sediments but are exposed in the pre-Cambrian rocks from which Triassic sediments have been removed. Because of their lithologic similarity and parallel trend all the diabase dikes are considered to be of Triassic age.

[50] Watson, T. L., Mineral resources of Virginia: Virginia-Jamestown Exposition Commission, p. 32, 1907.

[51] Laney, F. B., op. cit., p. 40.

STRUCTURE

TECTONIC HISTORY TO THE END OF THE PALEOZOIC ERA

The crystalline rocks of the southern Appalachian region lie in the southern part of a relatively narrow orogenic belt that is located on the eastern edge of the North American continent. This area was a mobile belt of the earth's crust from pre-Cambrian time through the Paleozoic era. The pre-Cambrian geosyncline located in it lay west of the highland Appalachia, which formed the eastern edge of the continent until Triassic time and furnished the material that was deposited in the Appalachian geosyncline to the west of it. West of the geosyncline was the central continental lowland, which has been a positive element of the continent throughout geologic time and was the foreland against which pre-Cambrian and Paleozoic folding was directed.

The thick sediments of the Glenarm series, of which the Wissahickon formation is a part, were deposited in the pre-Cambrian Appalachian geosyncline all the way from eastern Pennsylvania to southern Alabama. They are now exposed in the area of the Martic overthrust block and the Catoctin-Blue Ridge anticlinorium. Coastal-plain sediments now cover the eastern and southern parts of these pre-Cambrian rocks and Paleozoic sediments the western part.

The pre-Cambrian rocks were metamorphosed into crystalline schists of high-rank metamorphism during the pre-Cambrian folding that followed the deposition and were intruded by igneous rocks.

The Paleozoic Appalachian geosyncline was formed in this same orogenic belt, and the Paleozoic rocks were deposited on the eroded edges of the earlier series. The middle of this geosyncline lay west of the present Blue Ridge province, probably farther west and nearer to the foreland than its predecessor. Its eastern limit is problematical because only remnants of Paleozoic rocks are preserved in the Martic thrust block. In Pennsylvania and Maryland the eastern part of the geosyncline, in which deposition is known to have been nearly continuous from early Cambrian to late Ordovician time and probably later, is just northwest of the Martic thrust block, which overrode it in part. Southwest of Maryland this part of the basin, which extended westward from the region east of the present Catoctin-Blue Ridge anticlinorium, is covered entirely by this overthrust block.

When the whole Appalachian belt yielded to crustal folding in late Paleozoic time the area included in the present Piedmont, Blue Ridge, and Appalachian Valley and Ridge provinces was involved. The most intense folding and overthrusting occurred from the area of the Valley and Ridge province eastward, on the eastern or inner side of the Permian mountain range formed at that time. The rocks of the Martic overthrust and Blue Ridge anticlinorium and the Paleozoic rocks of the

Valley just west of the Blue Ridge were closely folded; the folds were overturned and broken by thrust faults. The intensity of folding decreased and died out westward in the plateau region on the outer side of the Permian mountain range. There the push of the folds resulted in the formation of the Cincinnati anticline and Nashville dome, which are vertical swellings in the foreland and part of the positive area of the continent that has persisted without folding throughout geologic time.

Granite was intruded in the inner part of the range after crustal folding ceased.

THE KYANITE BELT

The Martic thrust block lay east of the deeper part of the Appalachian geosyncline. It arose as a great fold in the late Paleozoic diastrophism. The fold was pushed northwestward to a horizontal attitude, its lower limb was drawn out and finally broken, and it was driven westward for 15 or 20 miles as a great overthrust fault, or nappe, over the rocks of the Catoctin-Blue Ridge anticlinorium. The anticlinorium at the same time arose and was pushed westward, so that it overlaps Paleozoic rocks of the Appalachian Valley and Ridge province, which are themselves folded and broken by overthrust faults.

The rocks of the kyanite belt are part of the Martic overthrust block. In central Virginia and southwestward it is broken by another thrust, the Appomattox, the trace of which is lost northeastward in the wide belt of Wissahickon albite-chlorite schist that lies in the western front of the Martic overthrust block.

In Pennsylvania and Maryland the core of the recumbent fold which gave rise to the Martic overthrust is exposed in anticlines of Baltimore gneiss and overlying basal members of the Glenarm series located on the southeastern edge of the Piedmont upland and not exposed in Virginia. The overlying younger pre-Cambrian rocks, chiefly the Wissahickon formation, form the front of the fold, which has overriden Paleozoic rocks lying in synclines between uplifts of the Catoctin-Blue Ridge anticlinorium and related uplifts in Pennsylvania and Maryland. The westward movement of the Martic overthrust was greater in Virginia, where it cuts pre-Cambrian rocks of the Catoctin-Blue Ridge anticlinorium and covers the southwestward extension of the Paleozoic sediments that are exposed in Maryland and Pennsylvania on the southeast side of the anticlinorium.

In the region of the kyanite belt the surface emergence of the Martic thrust lies west of the area here mapped near James River. Northeast of Lynchburg to southern Maryland this thrust block has been dropped by normal faults in respect to the rocks of the Catoctin-Blue Ridge anticlinorium west of it, but southwest of Lynchburg the contact of albite-chlorite schist with the Lynchburg gneiss on the west is an overthrust contact. The Appomattox thrust, which is a break in the Martic thrust whereby the eastern part of it has moved over the western part from Virginia southwestward, overrides the Wissahickon biotite gneiss that lies south of Pilot Mountain, Va. The thrust extends southwestward through Gladys, outside the area of the accompanying map (Pl. 2) and across Roanoke River. From the vicinity of Chalk Level, Va., to Rural Hall, N. C., the overthrust rocks are covered by Triassic sediments of the Dan River area.

The rocks of the kyanite belt were closely folded, and the folds are recumbent, with overturning to the northwest. These secondary folds took up the remaining stress after the main forward movement of the overthrust blocks, and they indicate the nature of the major structure of the area. The Wissahickon formation, the injection gneisses formed by intrusive hornblende gneiss and granite, and the granite itself have been folded and contain southeastward-dipping cleavage. In the discussion of the Wissahickon formation of the kyanite belt it was pointed out that in a large part of the area on the western border of the Appomattox and Martic thrust blocks the old foliation planes of the oligoclase-biotite schist were partly or completely transposed, and the schist exhibits the finely lenticular structure of a phyllonite. The minerals of the mesozone Wissahickon schist were at the same time broken and altered to epizone minerals, chlorite or muscovite, and the resultant rock is an albite-chlorite-muscovite schist or diaphthoritic phyllonite and not an epizone schist of progressive metamorphism. Also at the same time the intrusive Columbia granite was cataclastically deformed and converted into an augen gneiss and granite mylonite in the retrogressive zones. The kyanite belt contains unchanged remnants of mesozone Wissahickon schist, but the main belt of mesozone schist lies east of and outside of the kyanite area, in that part of the thrust block which did not rise high enough during the thrusting to be affected by retrogression and cataclasis.

The area west of the Appomattox overthrust shows a similar progressive degradation westward from a coarse-grained biotite-garnet-staurolite schist to a fine-grained albite-chlorite-muscovite schist on the western edge of the Martic overthrust block.

THE CRYSTALLINE BELT OF THE SOUTHERN APPALACHIAN REGION

The structure of the kyanite belt furnishes an epitome of the polymetamorphism and structure of the crystalline rocks of the southern Appalachian belt, which extends from Pennsylvania to Alabama. The kyanite belt lies in the Martic and Appomattox overthrust blocks and east of the Catoctin-Blue Ridge anticlinorium, which is a third great thrust block or nappe of the southern Appalachian region. These three overthrusts are the major structural units of the crystalline belt of the southern Appalachian region. Each overthrust block is made up largely of pre-Cambrian rocks of high-rank metamorphism with a wide western border of rocks of low-rank metamorphism, comprising retrogressive phyllonite and mylonitized granites produced along the sole of the thrusts during overthrusting.

In Maryland, Pennsylvania, and northern Virginia there is but one belt of highly metamorphic schists east of the uplifts of the Catoctin-Blue Ridge anticlinorium, and it grades northwestward into a belt of albite-chlorite schist 25 miles wide which forms the western edge of the Martic overthrust. This highly metamorphic belt in southern Virginia lies east of the Appomattox thrust and extends through Richmond, Raleigh, and southwestward. The Appomattox overthrust extends across Virginia and North Carolina west of Winston-Salem and Kings Mountain and east of Spartanburg, S. C.

The Appomattox overthrust overrides the central belt of highly metamorphic rocks which appears in the kyanite belt south of Appomattox Court House and extends southwestward through Chatham, Va., and Hickory, N. C. The rocks in this central belt of high-rank metamorphism grade by progressive degradation into diaphthoritic phyllonites along the western front of the Martic thrust block. The surface emergence of the Martic thrust crosses Virginia south of Lynchburg and Henry. It enters North Carolina southwest of Mount Airy and extends southwestward on the flank of the Blue Ridge crest north of Linville and Brevard, N. C.

The westerly belt of highly metamorphic rocks of the Blue Ridge anticlinorium lies west of the Martic overthrust from Virginia to north-central Georgia. The belt passes through Lynchburg, Rocky Mount, and Hillsville, Va., forms the crest of the Blue Ridge across North Carolina through Sparta and Asheville, and ends at the southwestern termination of the Blue Ridge crest east of Tate in northern Georgia. Northeast of Roanoke the western highly metamorphic belt is bordered by cataclastic igneous rocks and infolded Lower Cambrian rocks that lie on the western edge of the anticlinorium. This fold is overturned and has overridden Lower Cambrian and other Paleozoic rocks of the Appalachian Valley. It may be called the Blue Ridge nappe. Its surface emergence southwest of Roanoke is marked by retrogressive phyllonitic schists as well as mylonitized igneous rocks. It overrides basal Cambrian quartzite which forms the mountains of the northwestern border of the Blue Ridge province from Roanoke to northern Georgia—the Iron, Unaka, Holston, Great Smoky, and Cohutta mountains. The Lower Cambrian quartzites of these mountains are thrust over Paleozoic limestones which appear in fensters in North Carolina, Tennessee, and Georgia.

Throughout the southern Appalachian region, southwest of Pennsylvania, the great overthrusts are characterized by large areas of cataclastically deformed pre-Cambrian granites similar to the augen gneiss and granite mylonites in the Appomattox overthrust block. Many of these deformed pre-Cambrian granites have been called sedimentary schists[52] and quartzites by previous workers who did not recognize their original character and history.[53]

EVIDENCE OF OVERTHRUSTING

Exposures of thrust-fault contacts are few in the Appalachian region, and the existence of the extensive overthrust faults must be established on other evidence.

In Pennsylvania the pre-Cambrian Wissahickon albite-chlorite schist of the Martic overthrust has unconformable contacts with Lower Cambrian and Ordovician rocks lying to the north and northwest of it. The thrust contains fensters of Ordovician limestone, where erosion has cut through the Wissahickon schist on the northern edge of the thrust block.

In Virginia and farther southwest, where the Wissahickon formation is thrust over similar pre-Cambrian schists, fensters have not been recognized, and the above-described evidence of overthrusting is lacking. The polymetamorphic character of the metamorphism of rocks in the overriding mass, however, furnishes the needed clues to the major structure. In other words, the microtectonic study of the schists reveals the major tectonic history of the region.

The old explanation of the change from east to west in Pennsylvania and Maryland of the highly metamorphosed rocks to albite-chlorite schists and other rocks apparently of low-rank metamorphism is that the metamorphism died out toward the northwest. In central Virginia, where there is an alternation of zones of high-rank and low-rank metamorphism, the explanation was not applicable, and there the rocks of low metamorphic intensity were formerly called Cambrian.[54] Similar rocks in the Appalachian region to the southwest, in the front of the Appomattox overthrust in North and South Carolina[55] and in Georgia,[56] have been called Cambrian. The same interpretation has been given to

[52] Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Mount Mitchell folio (No. 124), pp. 4, 5, 1905; Pisgah folio (No. 147), p. 41, 1907.
Sloan, Earl, Mineral localities of South Carolina, pp. 226-230, 1908.
Galpin, S. L., Feldspar and mica deposits of Georgia: Georgia Geol. Survey Bull. 30, pp. 74-76, 119-191, 1915.

[53] These thrust faults and the metamorphic zones of crystalline rocks here described will appear on the geologic map of the United States, to be published by the United States Geological Survey in 1933, and the reader is referred to this map for further details of the stratigraphy and structure of the crystalline rocks of the southern Appalachian region.

[54] Geologic map of Virginia: Virginia Geol. Survey, 1916.

[55] Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Gaffney-Kings Mountain folio (No. 222), pp. 4-6, 1931.

[56] Adams, G. I., The significance of the quartzites of Pine Mountain in the crystallines of west-central Georgia: Jour. Geology, vol. 38, no. 3, pp. 271-279, 1930.

the rocks of low-rank metamorphism in the Martic and Blue Ridge thrusts in North Carolina, Tennessee, Georgia, and Alabama.[57]

Microscopic study of the schists of low-rank metamorphism has shown that instead of being less metamorphosed than the mesozone schists they have had superimposed on an earlier deep-zone metamorphism a second metamorphism which resulted in a retrogression and a breaking down of textures built up in the earlier metamorphic process. All gradations occur from medium-grained oligoclase-biotite schist containing garnet, staurolite, and kyanite to fine-grained albite-chlorite-muscovite schist with or without unstable relics of garnet and staurolite partly altered to chlorite and muscovite, of titanite, and of ilmenite altered to leucoxene. Such a rock is a diaphthoritic phyllonite, a product of retrogressive metamorphism, and not a phyllite formed by progressive metamorphism, because it had passed through a stage of high-rank metamorphism before it was converted into an epizone schist by a second metamorphism. Some of the so-called quartzite, itacolumite, and feldspathic quartz schists that are interlayered with the albite-chlorite-muscovite schists are cataclastically deformed granites whose constituents were rolled out into fine-grained dense ultramylonites. It is concluded, therefore, that the metamorphism exhibited in the crystalline schists is not a dying out process from east to west, nor are the phyllitic belts composed of less metamorphosed and younger rocks than those in the zones of high-rank metamorphism.

These conclusions that the mylonitized zones containing deformed granite and phyllonitized schists mark the emergence of thrust plates are in accord with those of E. B. Knopf[58] and other workers[59] in the southern Taconic area.

AGE OF STRUCTURAL FEATURES

The age of the metamorphism and overthrusting in the crystalline rocks of the kyanite belt and the southern Appalachian region in general is assigned to the late Paleozoic. There is no evidence that intense folding and metamorphism comparable to those of the Taconian[60] in New England affected the Appalachian region southwest of northeastern Pennsylvania in late Ordovician time. In southeastern Pennsylvania

[57] Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Asheville folio (No. 116), pp. 5-6, 1904; Mount Mitchell folio (No. 124), p. 5, 1905; Nantahala folio (No. 143), pp. 3-5, 1907; Pisgah folio (No. 147), p. 4, 1907.
LaForge, Laurence, U. S. Geol. Survey Geol. Atlas, Ellijay folio (No. 187), pp. 5-7, 1913.
Bayley, W. S., Geology of the Tate quadrangle, Ga.: Georgia Geol. Survey Bull. 43, pp. 47-103, 1928.
Adams, G. I., Geology of Alabama, with geologic map: Alabama Geol. Survey, Special Rept. 14, pp. 36-40, 1926.

[58] Knopf, E. B., Some results of recent work in the southern Taconic area: Am. Jour. Sci., 5th ser., vol. 14, pp. 457-458, 1927.

[59] Agar, W. M., The petrography and structure of the Salisbury-Canaan district of Connecticut: Am. Jour. Sci., 5th ser., vol. 23, pp. 32-45, 1932.

[60] Schuchert, Charles, and Longwell, C. R., Paleozoic deformation of the Hudson Valley region, New York: Am. Jour. Sci., 5th ser., vol. 23, p. 305, 1932.

there was uplift and erosion after Beekmantown time.[61] To the northwest in the area of the Appalachian Valley there was folding and erosion of Ordovician rocks, on which the Silurian rests unconformably as far as Harrisburg, Pa.[62] Southwestward there is no absence of the Upper Ordovician beds and no unconformity at the base of the Silurian.

The Blue Ridge nappe overrides thrust blocks of Paleozoic rocks which include some of Pennsylvanian age. Near Erin, Ala., pre-Cambrian schist phyllonitized in epi-Carboniferous time and called Talladega formation by the Alabama Geological Survey surrounds Carboniferous shales exposed in a fenster in the thrust block.

The undeformed granite, called the Petersburg granite in Virginia, is widely exposed in Virginia east of the kyanite belt and for the most part southwest of Richmond. Granite in Virginia and similar granite toward the southwest were intruded after Appalachian folding had ceased. The granite is not deformed; it cuts across older structural features without disturbing them and enters the rocks by replacing them. It was intruded in the eastern or inner part of the Permian range, mainly in the area of the Appomattox and Martic overthrust blocks. It occurs in the Roanoke and Atlanta recesses as well as in the Asheville salient. Its intrusion was the last event of late Paleozoic orogeny, and not the cause of mountain building, as has been claimed.[63]

The late Paleozoic granite of the southern Appalachian region intrudes, so far as known, only pre-Cambrian rocks, including schists of high-rank metamorphism, intrusive igneous gneisses, retrogressive phyllonites, and mylonitized igneous rocks. The metamorphism that formed schists of high-rank metamorphism was of pre-Cambrian age. The phyllonitization and mylonitization of these high-rank metamorphic schists and their intrusives occurred during the Appalachian orogeny along overthrust belts in which there was intense differential movement.

[61] Stose, G. W., and Jonas, A. I., Ordovician overlap in the Piedmont province of Pennsylvania and Maryland: Geol. Soc. America Bull, vol. 34, pp. 507-524, 1923.

[62] Stose, G. W., Unconformity at the base of the Silurian in southeastern Pennsylvania: Geol. Soc. America Bull, vol. 41, pp. 629-658, 1930.

[63] Keith, Arthur, Outlines of Appalachian structure: Geol. Soc. America Bull., vol. 34, pp. 321-322, 365-375, 1923.

Economic Aspects of Kyanite

By Joel H. Watkins

GENERAL FEATURES

Kyanite, sillimanite, and andalusite form what is commonly known as the sillimanite group of aluminum silicate minerals. These three minerals have the same chemical composition, $Al_2O_3.SiO_2$, but they differ somewhat in their crystallography, specific gravity, and other physical properties.

Contrary to popular belief, kyanite is not a mineral of recent discovery but is an old and well-known mineral, Dana,[64] giving one reference to its description as early as 1784. The minerals of the sillimanite group, however, have been brought into prominence in recent years on account of the important discovery that there are a number of uses in the field of ceramics to which they are well adapted.

OCCURRENCE OF KYANITE

Of the three minerals of the sillimanite group, kyanite is by far the most widespread and abundant. It is a common rock-forming mineral, being found in many places as a constituent of crystalline schists, gneisses, and quartzites which were derived from the older sediments. Notwithstanding its widespread distribution as a mineral substance, it has been found in commercial quantity in only a few places.

The color, crystalline structure, relative abundance, and associated minerals of kyanite vary widely in different localities. This variation is probably due in part to the chemical composition and in part to the physical character of the original sediments from which the crystalline rocks were formed by dynamic metamorphism. For example, in western North Carolina, within a comparatively short distance there are four distinct occurrences of kyanite: (1) Large lenses of almost massive kyanite segregations enclosing sapphire-blue corundum crystals, (2) disseminated in an enormous body of schist, with biotite, quartz, feldspar, garnet, and staurolite, (3) as large transparent crystals in true quartz veins cutting the schist, and (4) abundant bladelike crystals in a graphite-sericite schist.

In the crystalline schists and quartzites of the Appalachian region, kyanite may represent as low as 2 per cent or as high as 80 per cent of the rock of which it is a component.

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[64] Dana, J. D., A system of mineralogy, 2d ed., pp. 57 and 728, New York, Ivison, Blakeman, Taylor, and Co., 1784.

One of the earliest references to kyanite in Virginia was made by W. B. Rogers[65] who mentions the abundance of kyanite in a quartzose gneiss in Willis Mountain, in Buckingham County. At Baker Mountain in Prince Edward County, Virginia, kyanite occurs as deep greenish-blue bladelike crystals and as needle-like masses of radiating crystals in quartzite. The bladelike crystals are reticulated and vary from long thin crystals about the size of pencil lead to crystals one-fourth by half an inch in cross section and 2 to 3 inches in length. (See Pl. 6.) The radiating needle-like crystals occur in masses of fan-shaped groups and many are greenish.

In Baker Mountain, the kyanite content of the unaltered kyanitic quartzite ranges from 20 to 80 per cent, the average being probably well above 30 per cent. In Willis Mountain, about 40 miles northeast of Baker Mountain, the kyanite occurs also in quartzite, but it is mostly white instead of blue. Most of the crystals are bladelike and many are short and thick, though in general they are not as large as those in Baker Mountain. The kyanite content of the quartzite in Willis Mountain is also variable, but it has been estimated to average not less than 20 per cent of the rock.

Kyanite is known to occur at several other localities in Virginia, notably in Bull Mountain, Patrick County, near Galax and Fries in Grayson County (Pl. 7), and near Evington in Campbell County. Some prospecting has been done on the kyanite near Galax and Evington, but the value as commercial deposits has not been proven. (See Fig. 1.)

THE SILLIMANITE GROUP OF MINERALS

SOURCES OF MINERALS

In the Inyo Range, Mono County, California, Champion Sillimanite, Inc., has been mining andalusite since 1919. The Vitrefrax Corporation of Los Angeles, has mined a considerable tonnage of kyanite at Ogilby, California.

Near Charlotte Courthouse, Virginia, and near Burnsville, North Carolina, small kyanite mines are being developed in connection with pilot concentration mills. Each of these localities has large ore reserves and each will probably become an important producer. Besides the now well-known operations there are reported to be several small scattered developments in some of the western states. Kyanite is known to occur also at several localities in the Appalachian region where the deposits have not been developed.

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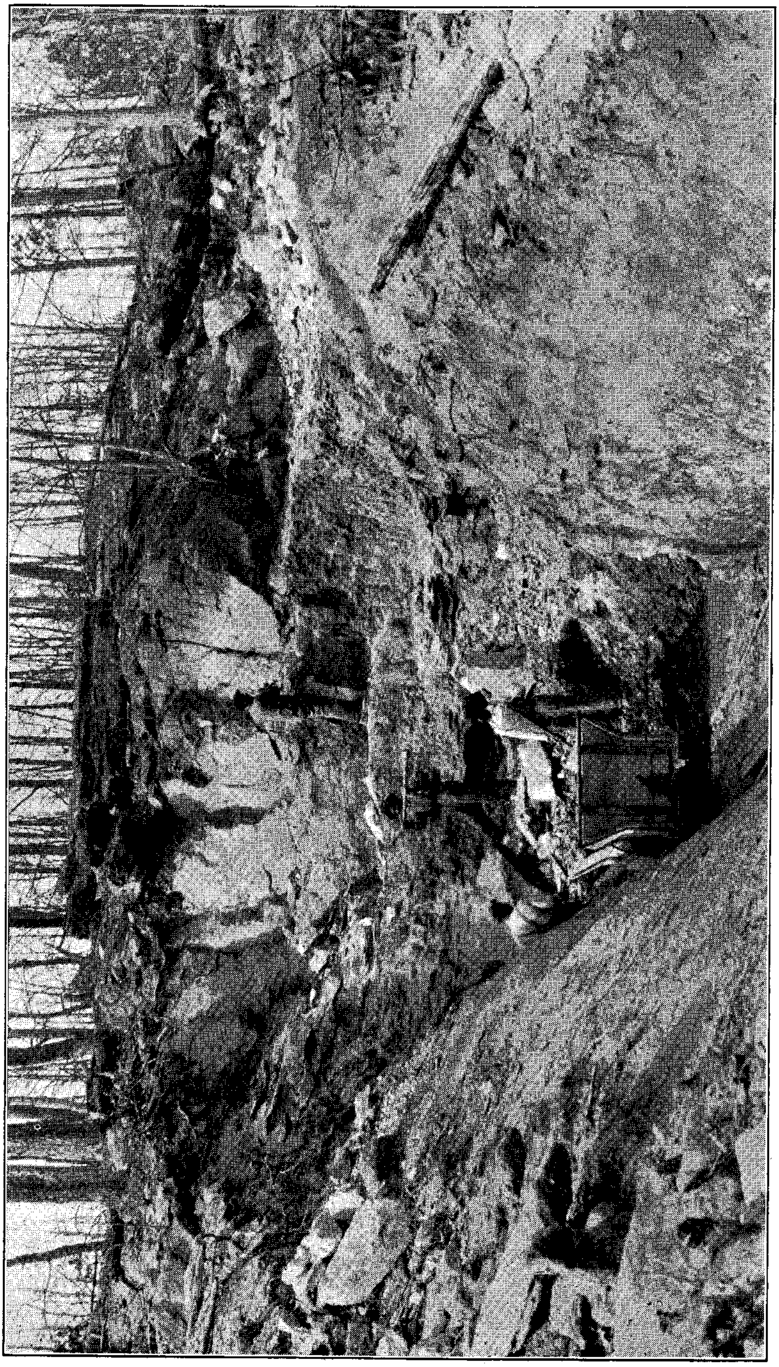
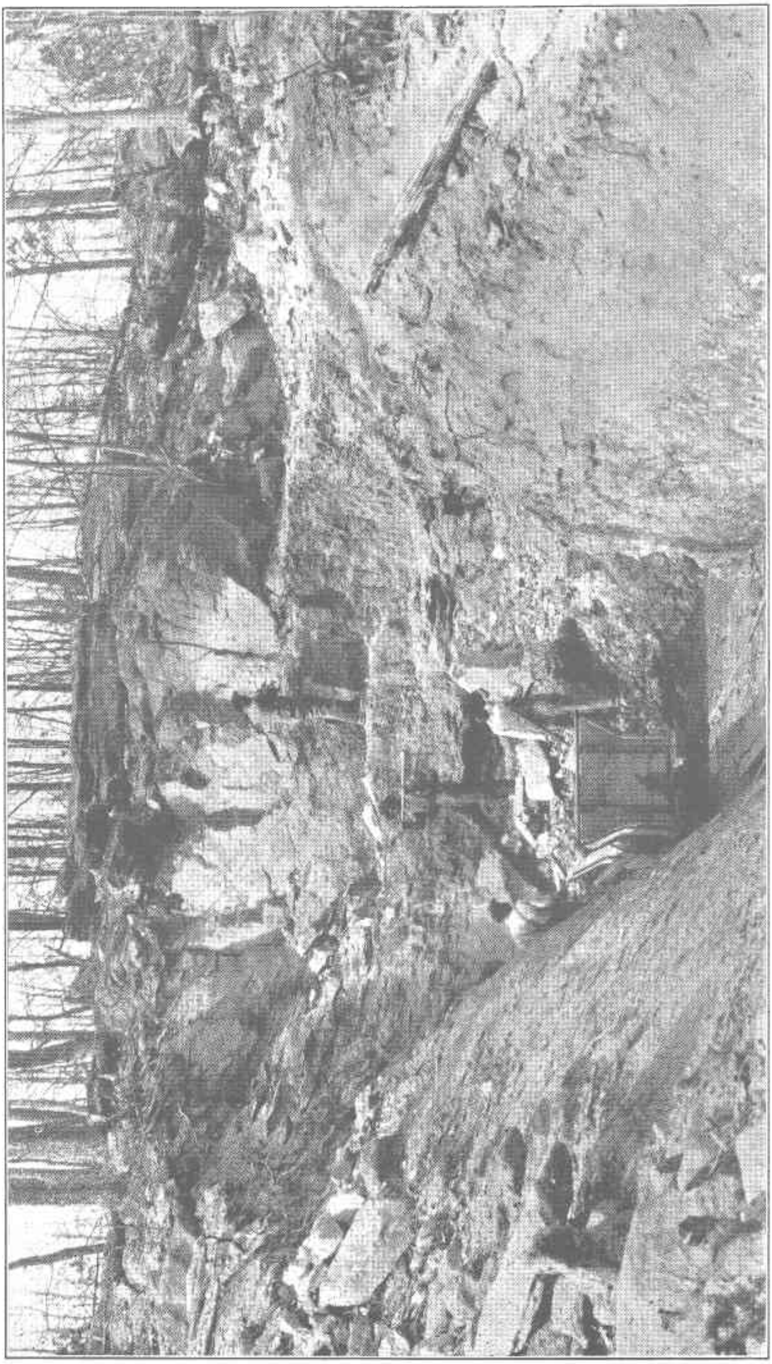
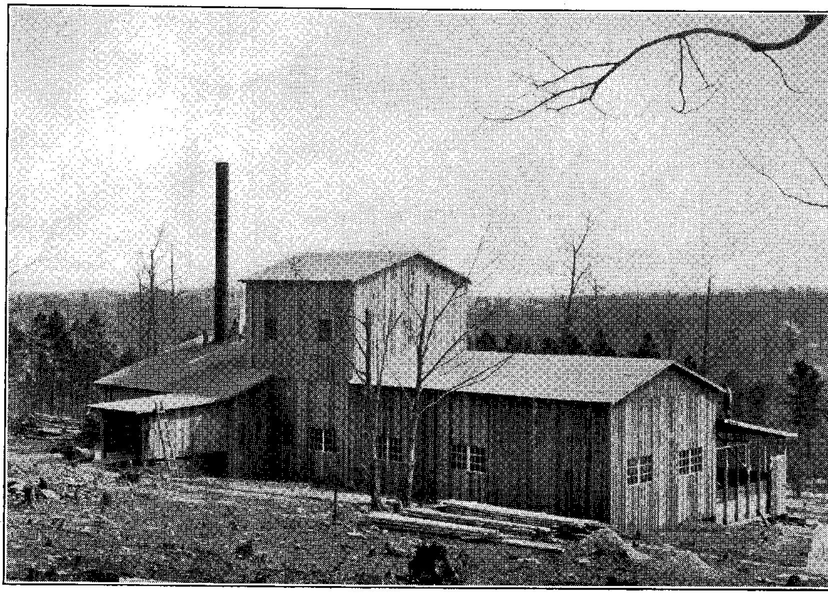
[65] Rogers, W. B., A reprint of annual reports and other papers on the geology of the Virginias, pp. 71-72, New York, D. Appleton and Co., 1884.



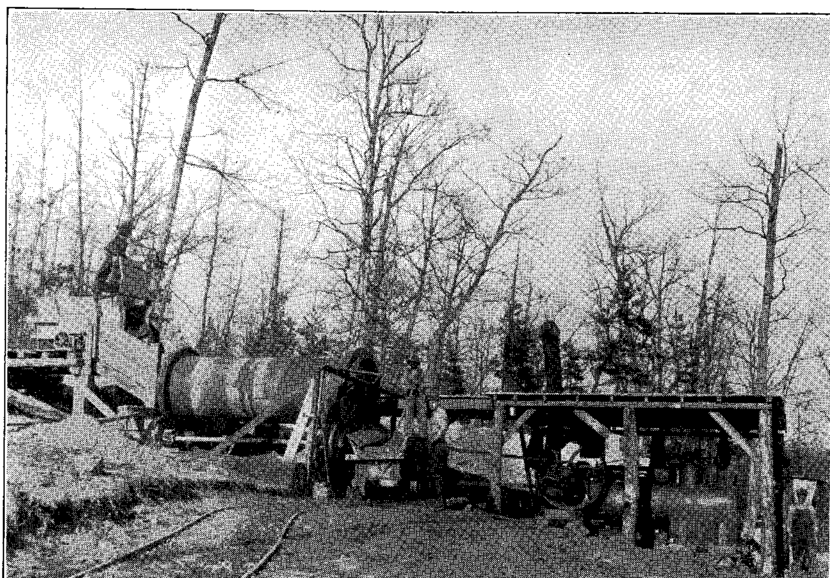
Pit in disintegrated kyanite-bearing rock at top of Baker Mountain, Prince Edward County



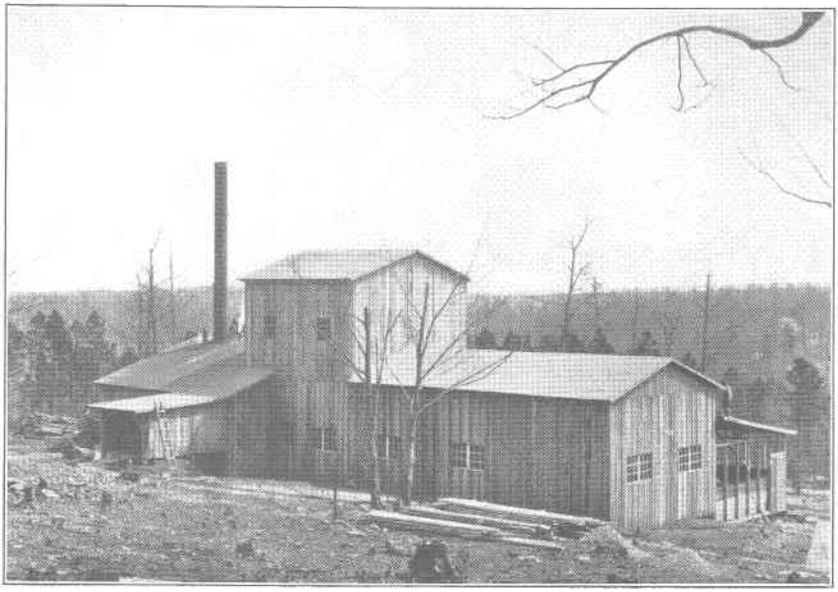
Pit in disintegrated kyanite-bearing rock at top of Baker Mountain, Prince Edward County



A. Experimental concentrating mill, McLanahan-Watkins Company, on Baker Mountain, Prince Edward County.



B. Cylinder washer for removing clay from disintegrated kyanite-bearing rock. McLanahan-Watkins Company, Baker Mountain.



A. Experimental concentrating mill, McLanahan-Watkins Company, on Baker Mountain, Prince Edward County.

B. Cylinder washer for removing clay from disintegrated kyanite-bearing rock. McLanahan-Watkins Company, Baker Mountain.

The Charles Taylor Company, Cincinnati, Ohio, is importing kyanite from the State of Kharsawan, India, where it occurs in a very pure state in boulders of unknown origin.

In addition to the natural kyanite and andalusite now being produced in the United States, several manufacturers are producing, in electric furnaces, a so-called synthetic sillimanite, which is in reality mullite.

METHODS OF TREATING ORES

The California andalusite, as produced by Champion Sillimanite, Inc., is massive and does not require concentration.

According to Riddle,[66] the Vitrefrax Corporation, at their Ogilby, California, plant uses an ingenious method of separating quartz and iron oxide from the kyanite ore. The ore is first calcined in a rotary kiln in which the iron oxide is reduced so as to be removed with a magnetic separator. In calcining, the quartz is converted from alpha quartz to beta quartz. The hot calcine falls into water which reconverts the beta quartz to alpha quartz. This rapid quenching causes the quartz to expand and then contract, producing a fine sand which is readily separated from the coarser kyanite calcine by slightly inclined shaking screens.

In Prince Edward County, Virginia, near Charlotte, Courthouse, the McLanahan-Watkins Company uses a simple wet gravity process for concentrating the kyanite ore. Overlying the hard fresh rock is a mantle of partially decomposed rock and residual clay which is from 40 to 50 feet in depth. (See Pl. 10.) The kyanite crystals and much of the quartz being resistant to the agencies of rock weathering, remain in the clay, and are easily removed by washing and screening. A small cylinder washer is used for the preliminary scrubbing. (See Pl. 11.) The mill feed, as taken from the washer, carries about 50 per cent kyanite crystals. No primary crusher is used, the mill feed passing over the belt conveyor direct to a rod mill. From the rod mill the material is elevated to a vibrating screen from which it passes through a launder and vortex classifiers to shaking tables. The oversize from the screen goes back to the rod mill for regrinding. As the tables are much more efficient with a coarse-grained feed than with a fine-grained feed, a very light load of rods is used in the mill for the initial grinding, in order to crack the crystals instead of pulverizing them. The concentrates, as produced by the preliminary tabling, are roughly of 10-mesh size and smaller. For fine grinding, that is, to 40-mesh size and less, the coarse cencentrates are reground with a heavy load of rods and then retabled.

As the quartz grains are rounded and the kyanite crystals are bladelike and elongate, screening may be used to great advantage in the

[66] Riddle, F. H., Minerals of the sillimanite group: Eng. and Min. Jour., vol. 133, no. 3, p. 141, 1932.

ultimate flow sheet. Effective and inexpensive methods for removing the iron oxide have been worked out, but no equipment has been installed for removing the iron in order to produce a concentrate of low iron content.

The concentrates, as at present produced, contain from 90 to 95 per cent kyanite. The present capacity of the pilot mill is about 8 tons of coarse-grained concentrates in 10 hours.

Celo Mines, Inc., at Burnsville, North Carolina, use a dry process in concentrating the ore. The rock is first reduced to three-fourths inch size with a jaw crusher, and is then ground in a rod mill in closed circuit with a vibrating screen. The associated minerals, garnet, staurolite, quartz, feldspar, and biotite are then separated by means of an induction magnetic separator and an electrostatic separator. The material is prepared in various degrees of concentration up to 98 per cent kyanite, with a very low iron content.

ASSOCIATED MINERALS

Baker Mountain in Prince Edward County, is made up essentially of a kyanite-bearing quartzite which contains some pyrite, and 2 to 3 per cent rutile. A very small amount of muscovite is present in places. In the oxidized zone, the pyrite has been converted to iron oxide, which partly replaces a small amount of kyanite and quartz. The rutile occurs in small red crystals and scales, most of which on grinding separate from the kyanite and quartz and can be readily saved on the concentrating tables. No garnet, feldspar, biotite, staurolite, hornblende, or other objectionable minerals have been observed in the quartzite on Baker Mountain.

On Willis Mountain, Buckingham County, the associated minerals are the same as in Baker Mountain, though the rutile content is somewhat smaller.

PYROCHEMISTRY OF ALUMINO-SILICATE MATERIALS

Natural alumino-silicate materials may be divided into two general classes: (1) Amorphus or claylike materials, and (2) crystalline minerals. The pyrochemistry of alumino-silicate materials, both clays and minerals, is one of the oldest and best known of the industrial arts. Since glasses and metals have been melted and pottery has been burned, alumino-silicate materials (mostly clays) have been used in such refractory bodies as crucibles, fire brick, furnace linings, and kiln linings, where high temperatures, molten materials, and hot gases have had to be handled.

Until comparatively recent times, actual knowledge of the pyrochemistry of clay refractories and clay pottery wares has, for the most part, been obtained by practical experience, rather than by scientific research. In the past decade, however, marked advances have been made in both the knowledge and uses of alumino-silicate refractories and porcelain wares. This advance in the technology and pyrochemistry of alumino-silicate materials is due, in large part, to the rapid development of the relatively new science of ceramic engineering.

All clays are hydrous aluminum silicates. Clays may range from a high silica content to a high alumina content, with varying amounts of such impurities as iron oxide, titanium oxide, and oxides of the alkali group. As the result of exhaustive research by ceramic engineers, followed by service tests and commercial applications, it has been found that, in many cases, crystalline alumino-silicates have decided advantages over the amorphous varieties when used in the bodies of both refractories and porcelain wares.

Crystals of mullite, $3Al_2O_3.2SiO_2$, have long been observed microscopically in practically all alumina-silica refractories, especially after having been in service. Crystals of the compound $3Al_2O_3.2SiO_2$ have been mistaken for sillimanite, $Al_2O_3.SiO_2$, on account of the similarity of their optical properties.

Natural minerals of the sillimanite group occur in the ratio 1:1 ($Al_2O_3.SiO_2$) of the alumina-silica system. Exceptions to this rule have been noted only where shales and related rocks have been heated as a result of contact with, or immersion in, igneous magmas. Bowen[67] has described crystals of $3Al_2O_3.2SiO_2$ from the Island of Mull off the coast of Scotland, and suggested the name mullite for the compound.

Bowen and Greig[68] were the first to discover that $3Al_2O_3.2SiO_2$, the 3:2 ratio, is the only stable compound of alumina and silica at high temperatures, up to 1,810°C.

When natural sillimanite is heated to temperatures above 1,545°C, the compound breaks up into $3Al_2O_3.2SiO_2$ and a highly siliceous glass. If the compound $3Al_2O_3.2SiO_2$ is heated to temperatures above 1,810°C, it will melt incongruently and break up into corundum and liquid. A slight excess of silica over the 3:2 ratio will lower the melting point of a charge, whereas a slight excess of alumina will raise the melting point. This discovery has been of great value to the ceramic engineer in working out equilibrium relations of mixtures of alumina and silica.

USES OF KYANITE

As stated above, kyanite is not a new mineral but is an old mineral for which new uses have been found. Riddle suggested replacing feldspars in electrical porcelain bodies with crystalline alumino-silicate

[67] Bowen, N. L., Mullite, a silicate of alumina: Washington Acad. Sci., Jour., vol. 14, no. 9, pp. 183-191, 1924.

[68] Bowen, N. L., and Greig, J. W., The system $Al_2O_3.SiO_2$: Am. Ceramic Soc. Jour., vol. 7, no. 4, pp. 238-254, 1924.

minerals which carry no alkali. This suggestion led to initial research in the use of high aluminium silicates in spark plug porcelains. Since 1919, the Champion Porcelain Company has been using, in all of its spark plug cores, andalusite mined in California. This laboratory research with alumino-silicate minerals soon brought to the attention of the ceramic engineer the valuable refractory properties of the minerals of the sillimanite group. There is probably not a ceramic research laboratory in this country today in which some work has not been done with high aluminum-silicate minerals, either in refractories or in porcelain bodies. The universal use of the minerals of the sillimanite group in the field of silica and clay refractories has not developed as rapidly as predicted by the ceramic engineer. There are now four producers of artificial sillimanite, and at least one importer of natural kyanite.

Many and varied uses have been found for the minerals of the sillimanite group, the most important of which are enumerated below. The rather high price of the raw material has probably been the greatest drawback to its more extensive use. In a recent article, Riddle[69] states, "At present, cost is the limiting factor in the almost universal use of sillimanite wherever fireclay, silica, high-alumina, or kaolin brick are used." The prediction is here made that the answer to the question of high cost will be met by large-scale, low-cost production from some large bodies of kyanitic rock in some of the southern Appalachian States.

It has been found that the properties which make kyanite valuable as a constituent in refractory and porcelain bodies are: (1) Its high melting point, (2) high thermo-dielectrical resistance, (3) low coefficient of expansion, and (4) its resistance to the corrosive action of certain fluxing agencies and furnaces gases.[70]

In electrical porcelains, kyanite or its equivalents, besides producing a much higher dielectrical resistance than bodies using feldspar, adds greater strength and toughness to the bodies. The minerals of the sillimanite group on account of the increased strength and toughness which they impart to porcelain bodies, have been recommended for use and are used to some extent in sanitary ware and in hotel ware, where the breakage is high.

Refractories using chiefly the minerals of the sillimanite group have been found to be especially well adapted to service in glass house refractories, crucible furnaces, brass melting furnaces, electric furnaces, forging furnaces, tunnel car tops, saggers, high temperature cements, monolithic construction, oil- and gas-fired fire boxes, combusion tunnels, boiler furnaces, cement kiln linings, and other special applications.

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[69] Riddle, F. H., Minerals of the sillimanite group: Eng. and Min. Jour., vol. 133, no. 3, pp. 141-142, 1932.

[70] For a general discussion of kyanite and related minerals, see Petar, Alice V., Sillimanite, kyanite, andalusite, and dumortierite: U. S. Bur. Mines Information Circular 6255, March, 1930.

PRICES OF KYANITE

Bole[71] gives the following range of prices for special high-alumina silica refractories: Corhart fused mullite, standard shapes, $200.00 a ton; P. B. sillimanite refractories (Chas. Taylor Co.), 9-inch brick $500.00 a thousand; Babcock and Wilcox calcined kaolin fire brick $260.00 a thousand; 9-inch diaspore brick (70 per cent alumina) $145.00 a thousand.

Kyanite, in lump or concentrated form, is quoted at from $25.00 to $80.00 a ton according to purity and grain size, or whether calcined or raw.

[71] Bole, G. A., The alumino-silicate refractories: Metals and Alloys, vol. 3, no. 1, 1932.

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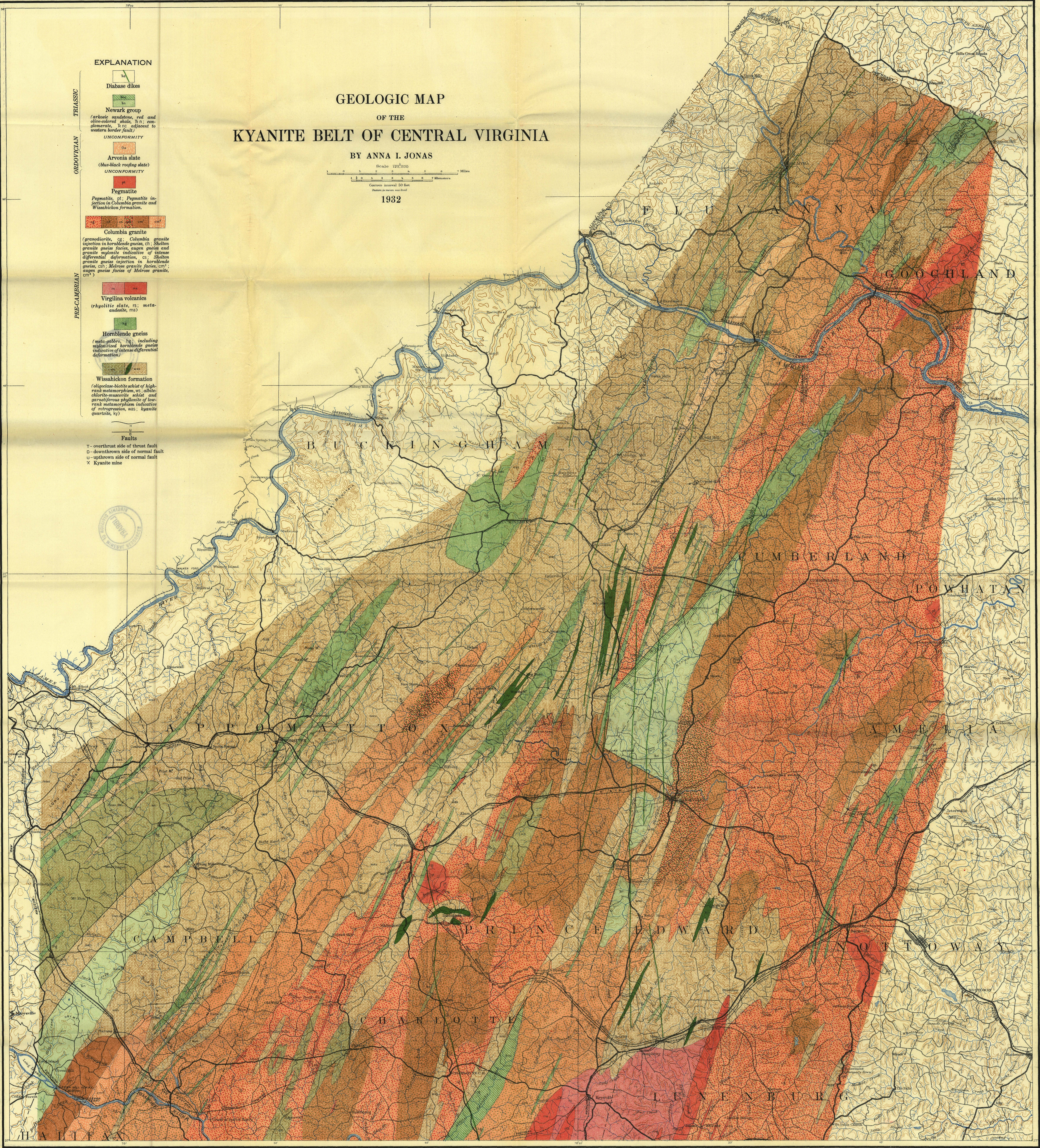

Base from United States Geological Survey maps of Appomattox, Buckingham, Farmville, Lynchburg and Palmyra quadrangles. Surveyed in 1888-1890. Railroads approximate; roads partly corrected.

Geology by Anna I. Jonas
Surveyed in 1929-31