Geologic Setting of the Hamme Tungsten District North Carolina and Virginia

GEOLOGICAL SURVEY BULLETIN 1122-G

Prepared in cooperation with the North Carolina Department of Conservation and Development, Division of Mineral Resources

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By JOHN M. PARKER 3D

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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Geology of the northeastern part of the Carolina slate belt. Prepared in cooperation with the North Carolina Department of Conservation and Development, Division of Mineral Resources

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GEOLOGIC SETTING OF THE HAMME TUNGSTEN DISTRICT, NORTH CAROLINA AND VIRGINIA

By John M. Parker 3d

ABSTRACT

The Hamme tungsten district is in the eastern part of the Piedmont province, mainly in Vance County, North Carolina, but it extends a few miles into Virginia. The district is underlain by a central lenticular pluton of albite granodiorite that trends north-northeastward and is flanked on both sides by metamorphic rocks of low and medium grade that dip steeply westward. The relative ages of the metamorphic rocks are uncertain. The oldest rocks are likely to be the biotite gneisses in the eastern part of the district; successively younger units exposed westward across the district are sericite-chlorite phyllites, greenstone, metafelsites, and metabasalts.

The biotite gneisses and minor intercalated hornblende gneiss, which have a total thickness of many thousand feet, were derived from sediments. Some of the gneiss grades into phyllites and was probably formed by metasomatic alteration of the phyllites. Sericite-chlorite phyllite, epidote-quartz metasiltstone, quartzite, and conglomeratic phyllite occur principally in a wide belt on the west side of the central albite granodiorite. This unit is some 10,000 feet thick and originally consisted mainly of sediments of the graywacke suite. Greenstone totaling about 500 feet in thickness lies west of the phyllite and was derived from mafic lava flows and andesitic tuff. Metamorphosed massive aphanitic and porphyritic flows and dikes that range in composition from dacite to rhyolite, and phyllitic metatuffs and tuffaceous breccia are exposed west of the greenstone. These total at least 3,000 feet in thickness. Massive metabasalt that resembles greenstone but is less altered is common in the area between the Hamme district and the Virgilina district to the west. The thickness of the metabasalt is about 600 to 6,000 feet.

The metamorphic rocks of the Hamme and Virgilina districts are parts of the Carolina slate belt, but map units cannot be directly correlated. Rocks in the Hamme district are thought by the writer to have been derived mainly from graywackes and volcanic flows, and subordinately from pyroclastic materials, whereas the rocks of the Virgilina district were interpreted by earlier workers as being mainly volcanic with much pyroclastic material but little sediment.

Igneous, and perhaps pseudoigneous, rocks in the district include hornblende gabbro, albite granodiorite, aplite, and pegmatite—all of which are probably middle Paleozoic in age—and diabase and hypersthene tonalite of Late Tri-

assic age. The gabbro forms three lenticular to subcircular bodies up to 2½ miles in width in the western part of the area. Albite granodiorite forms a pluton with a maximum width of 7 miles which occupies the center of the area. At its northeastern end the pluton narrows abruptly to a point. Phyllite forms the wallrocks on all sides of the albite granodiorite. The contact is gradational and conformable in most places, but on the northwest side it cuts across wall structure for about 3 miles. Near its western edge the albite granodiorite includes a northeast-trending zone of schistose wallrock, in and near which are localized the tungsten deposits. The origin of the albite granodiorite is uncertain, but it may have formed by the metasomatic replacement of the wallrocks, during which albite porphyroblasts developed first and were followed by microcline and quartz. Diabase and hypersthene tonalite occur as dikes and sills along four northward-trending belts. The dikes are a few feet to more than 300 feet thick, and several extend along strike for more than 10 miles.

The Hamme district is in the eastern part of the Carolina slate belt, and the Virgilina district lies along the western side of the belt. Rocks in the Hamme district dip mostly westward and in the Virgilina district dip mainly eastward into a syncline. This syncline, here named the Spewmarrow syncline, may be a structure of regional significance.

Tungsten in the Hamme district occurs mainly as huebnerite (manganese tungstate), with minor scheelite, in lenticular quartz veins. Associated minerals include fluorite, pyrite, galena, tetrahedrite, sphalerite, chalcopyrite, and others. The veins are in a narrow northeast-trending belt that is 7½ miles long. The great majority and the richer veins are concentrated in a 2-mile stretch near the middle of the belt. They occur in phyllitic rock and in albite granodiorite, near the western contact of the pluton. The deposits were discovered in 1942 and subsequently have been extensively developed. Production until August 1954 totaled 577,000 short ton units of tungsten trioxide valued at $27½ million.

INTRODUCTION

GENERAL SETTING AND LOCATION

The Hamme tungsten district, named for its discoverers, Joseph and Richard Hamme, is mainly in northwestern Vance County, N.C., but extends a few miles into south-central Mecklenburg County, Va. (See fig. 1.) The center of mining is about 13 miles north-northwest of Henderson, N.C., and about 9 miles southeast of Clarksville, Va. Access from U.S. Highways 1 and 15 is by North Carolina Route 39 and other paved but unnumbered roads. A branch of the Southern Railroad passes 4 miles to the west, and the main line of the Seaboard Airline Railway is 12 miles to the southeast.

The deposits are directly south of the John H. Kerr Reservoir, formerly named Buggs Island Reservoir, in the drainage area of Island Creek, a tributary to the Roanoke River. This valley has been shut off from the reservoir by a subsidiary dam in order to prevent possible flooding of the mines. Its drainage is pumped to the reservoir from a small collecting basin called Townsville Lake.

The topography of the district consists of rather flat to gently rolling uplands with elevations ranging from 350 to 450 feet, trenched

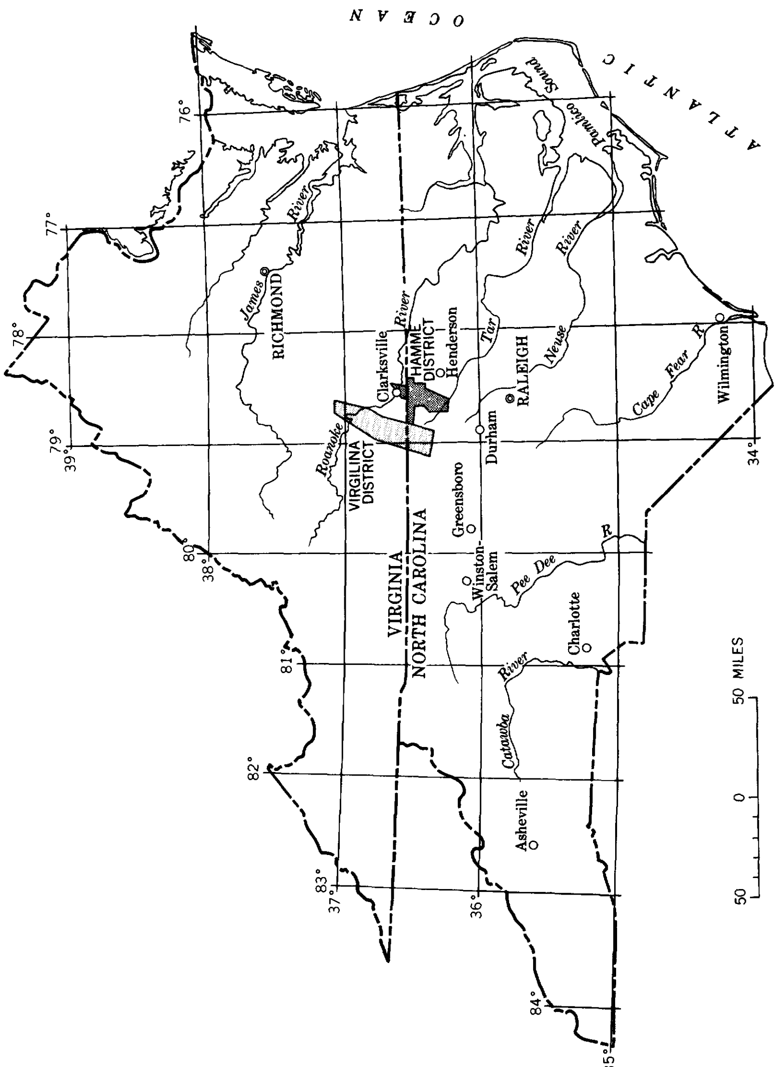

FIGURE 1.—Index map showing location of Hamme tungsten district and Virgilina copper district, North Carolina and Virginia.

by the Roanoke River and its tributaries to depths of 50 to 150 feet. The valley sides are moderately steep and, in a few places along the Roanoke, there were rocky bluffs before their inundation by Kerr Reservoir. The larger streams have developed flat, sediment-covered flood plains, which are less than 100 feet wide along some tributaries and as much as 3,500 feet wide in places along the river. Most of the land surface is covered by deep residual soil, and most upland areas have also a veneer of sediment. Rock exposures, thus, are few and scanty, in general occurring only along tributaries that have negligible flood plains, in road and railroad cuts, and in gullied fields. Most of the outcrops are more or less weathered; unaltered rock is rarely found. More than half the area is second-growth woodland, and the vegetation along the streams is dense. Because of these conditions, many desirable details of geology were not obtained.

The central part of the district is underlain by albite granodiorite, and to the east are steeply dipping gneisses, and to the west a variety of metamorphosed sedimentary and volcanic rocks of low grade. Quartz-huebnerite veins occur in a north-trending belt that is nearly 8 miles long and half a mile wide and that parallels a contact between albite granodiorite and phyllite.

The south end of the Virgilina copper district lies some 20 miles west of the Hamme tungsten district, extending nearly 40 miles north-northeastward into Virginia.

PREVIOUS INVESTIGATIONS

Geological investigations in the vicinity of the tungsten deposits are not known prior to their discovery in 1942. Pratt (1901, p. 32) states, "Wolframite has been reported as occurring in some quantity on the Cheek farm, near Henderson, Vance County," but when or by whom this report was made is not recorded. It is presumed, although not definitely known, that this refers to the locality of present mining.

In February and March 1943, W. A. White (1943, 1945) mapped about 2 square miles in the center of the district for the Division of Mineral Resources of the North Carolina Department of Conservation and Development. Work by the U.S. Geological Survey began with a brief examination by A. H. Koschmann and R. J. Wright in March 1943. Detailed large-scale mapping was carried on between July and December 1943 by a Geological Survey party that was headed by G. H. Espenshade (1943, 1947, 1950) and included R. J. Wright, M. H. Staatz, T. W. Amsden, E. A. Brown, and N. D. Raman. C. J. Cohen, geological engineer of the Bureau of Mines, also participated in some of the mapping. This work was coordinated with concurrent exploration by the Bureau of Mines (Argyle, 1946; McIntosh, 1948). The underground workings were mapped in April 1944 by C. F. Park, Jr., and G. H. Espenshade, and again in October 1944 and July 1945 by the latter.

Concern as to possible flooding of the deposits by the Kerr Reservoir prompted further exploration and testing between October 1947 and March 1948. This investigation was made for the Corps of Engineers, U.S. Army, by the U.S. Geological Survey and the U.S. Bureau of Mines, under the direction of an Advisory Board composed of L. C. Glenn, E. B. Burwell, G. H. Espenshade, M. H. Kline, and R. B. McKeagney. Additional drilling and trenching, sampling, and mapping were done. The Geological Survey party was composed of G. H. Espenshade, in charge, Louis Pavlides, A. W. Postel, and G. A. Rynearson. The results are contained in a report to the District Engineer, Norfolk District, Corps of Engineers (Glenn and others, 1948).

PRESENT INVESTIGATION AND ACKNOWLEDGMENTS

General geologic mapping of the district by the U.S. Geological Survey, the basis of the present report, was begun in August 1949 and continued during the summers of 1950–53 inclusive by the writer with various field assistants and between January 25 and March 1, 1954, by M. H. Staatz. During these periods a total of about 9 months was spent in the field.

Mapping was begun in Virginia in the valley of the Roanoke River, and the western contact of the central mass of albite granodiorite was traced northeastward to ascertain whether additional tungsten deposits occurred in association with this contact. A strip 1 to 1½ miles wide paralleling the contact was mapped in Virginia. In subsequent seasons the mapping was extended southward and then westward, the lowlands being studied before they were inundated by the John H. Kerr Reservoir.

General mapping was done at a scale of 1:10,000 on topographic base maps and airphotos supplied by the Corps of Engineers. About 106 square miles were covered. (See pl. 1.) The map of the central part of the district, which comprises about 9 square miles and was prepared by Espenshade (1947, pl. 1) and his party, was incorporated into the present map; and the marginal parts were reexamined in order to match contacts. During general mapping an effort was made to find and examine every outcrop in the area.

Study of the tungsten deposits was not included in the areal investigation.

Reconnaissance mapping of about 129 square miles, using U.S. Geological Survey quadrangle topographic maps and North Carolina Highway Commission road maps at a scale of 1 inch to 1 mile, was extended to the west and southwest of the area of general mapping. (See pl. 2.) During reconnaissance, rapid traverses were made along roads, and the data thus obtained were supplemented in critical places by further examinations away from roads. Only major rock groups were delineated.

Field data were compiled, 69 specimens were studied microscopically, and the report was written between field seasons, during the summer of 1954, and in June 1956. A preliminary account of the geology of the district was presented in 1953 (Parker, 1953, p. 1534). Thorough investigation of the district would require additional field and petrographic work.

The following assisted in the fieldwork: M. B. Corriher, 1949 season; R. S. Houston, 1950 season; W. G. Steel, 1951 season; C. M. Llewellyn, Jr., 1952 season; and D. R. Thompson, 1953 season. G. H. Espenshade introduced the writer to the district and conferred on part of the mapping. M. H. Staatz mapped about 12 square miles of the southwest corner of plate 1. R. A. Laurence supervised the project and conferred in the field.

Officials and employees of the Tungsten Mining Corp. cooperated wholeheartedly in the study. Mr. J. R. Sweet, general manager, supplied data on production for publication.

The work after the 1949 season was done in cooperation with the Division of Mineral Resources of the North Carolina Department of Conservation and Development. Dr. J. L. Stuckey, State Geologist, reviewed the report.

Residents of the district were uniformly interested in the work and helpful in many ways, especially in pointing out rock exposures in an area largely overwhelmed by vegetation.

The writer is indebted and grateful to all with whom he has been associated in the investigation.

GEOLOGY OF THE DISTRICT

The dominant geologic unit of the Hamme tungsten district is a central north-northeast-trending lens of albite granodiorite. (See pl. 1.) Phyllites form a sheath on both sides and around the north end of this lens. The phyllites are derived largely from sediments and in part, probably, from pyroclastic material. The eastern side of the mapped area is underlain by gneisses of medium grade, and the western part by a series of metavolcanic rocks of low rank, largely lava flows, many of which have little foliation. Intrusive into these are large hornblende gabbro lenses, aplite and pegmatite dikes and sills, and later dikes and sills of diabase and hypersthene tonalite. Quartz veins and narrow siliceous belts are numerous. Surficial deposits include sediment that caps most flat uplands and alluvium in the flood plains. Foliation and bedding strike generally north-northeast and dip steeply northwest. Lineations that consist of mica streaks in gneiss and of crenulations in phyllite are generally almost horizontal. Small-scale folds and faults are common. One syncline that is a few miles wide occurs between the Hamme and Virgilina districts. Joints are poorly developed. Quartz-huebnerite veins occur in a narrow belt that follows the west contact of the central lens of albite granodiorite.

Many more kinds of rocks are known to exist in the district than were mapped, and the units that are shown are composites. The different rock varieties commonly compose bodies too thin to map on any reasonable scale. These are interlayered with more or less strongly contrasted types; thus, for each outcrop or small area, it was necessary to decide what rock type predominated and to delineate generalized, composite lithologic units.

Only quartz veins, siliceous zones, and diabase dikes could be traced across country. Contact lines between other map units were so drawn as to separate areas underlain dominantly by rocks of one type from those where another predominates; thus, many contacts were of necessity drawn through areas lacking outcrops, and nearly all contacts are to be judged approximate or inferred.

METAMORPHIC ROCKS

Metamorphic rocks underlie both the eastern and the western sides of the district. All are rocks of the greenschist and albite-epidote-amphibolite facies and have been derived from both sedimentary and volcanic parent material by low-grade regional dynamic metamorphism. Their relative ages are not known with certainty. From east to west the group includes, in order of presumed decreasing age, biotite gneisses, sericite-chlorite phyllites, greenstone, metafelsites, and metabasalts. These rocks are intimately interbedded, and the map units are composite, commonly with gradational boundaries. Where contact lines are shown at oblique angles to foliation symbols (pl. 1), the actual boundaries are believed by the writer to be conformable but to zigzag intricately around interfingering thin lenticular rock bodies. The map contacts, then, show average or generalized positions of complex boundaries that are too poorly exposed and of too small scale to portray in detail. Foliation is characteristically parallel to bedding.

The biotite gneisses include equigranular, porphyroblastic, and microcline augen varieties, as well as some interbedded phyllite, hornblende gneiss, and biotite schist. They are interpreted as metasedimentary rocks. The phyllites contain layers of quartzite, meta-arkose, and conglomeratic rock and appear originally to have been mainly a sequence of detrital sediments of the graywacke suite. Greenstone ranges from a dark, fairly massive or poorly foliated, and nearly aphanitic chlorite-epidote rock to a readily cleavable chlorite phyllite. Some massive greenstone is amygdaloidal. The greenstones have been derived from mafic tuffs, breccias, and flows. The light-colored metafelsites are largely aphanitic massive rocks that appear to have been felsic lava flows and tuffs. The metabasalts consist mainly of very massive little altered black aphanitic rocks that are porphyritic or amygdaloidal in part, but in places the metabasalts include varieties that are more or less foliated. These originally were mainly basaltic lava flows.

The relative ages of the metamorphic rocks are uncertain. The whole sequence dips steeply westward toward the Spewmarrow syncline (pls. 1, 2) and so is presumed to be younger in that direction. Primary features indicating the tops of the beds were not observed. In conglomeratic phases of the phyllite, no pebbles of the rocks lying to the west were noted. Actual contacts of the rock units were not exposed, but they have conformable orientations. Phyllite and gneiss are gradational and interbedded and so are likely to be of similar age. Some gneiss is thought to have been formed by metasomatic alteration of phyllite. The gneiss is tentatively placed as the oldest unit because it lies farthest east in the westward-dipping sequence and is the most coarsely recrystallized rock, hence probably the most deep seated. The metamorphic rocks are regarded, from their regional relations, as probably of early Paleozoic age.

BIOTITE GNEISSES

The eastern side of the district is underlain by a thick series of north-northeast-trending gneisses. The maximum outcrop width mapped was 3½ miles (pls. 1, 2), but the gneiss belt is known to extend about 5 miles farther eastward, where it is succeeded by monazite-bearing granite (Mertie, 1953, p. 26). This belt of gneisses is designated on the "Geologic Map of the United States" (Stose and Ljungstedt, 1932) as Wissahickon schist with igneous injection, a part of the Glenarm series. It is believed to extend northward across all or most of Virginia and southward more than halfway across North Carolina before being buried by overlapping Coastal Plain sediments. In the Hamme district, the gneisses lie just east of the narrow phyllite strip which separates them from the central mass of albite granodiorite.

Rocks in the gneiss belt exhibit considerable variety, but most are medium-grained well-foliated biotite gneisses. The three principal types are: equigranular biotite gneiss, porphyroblastic biotite gneiss, and coarse microcline augen gneiss. These are gradational into one another. All occur at intervals throughout the gneiss belt except the coarse microcline augen gneiss, which is localized along the west side next to the phyllite strip. Thin layers of biotite-quartz schist and hornblende gneiss are interbedded throughout the gneisses and constitute a minor, unmappable part of the sequence.

The equigranular biotite gneiss is fine to medium grained, well foliated, and distinctly laminated. In hand specimen it is seen to consist of quartz, microcline, plagioclase, biotite, and muscovite. The amount of biotite varies abruptly from layer to layer; some layers contain 10 percent or less and are light gray and granitic, whereas other layers contain more than 50 percent mica and are black and schistose. Quartz predominates over feldspar in some light-colored rock that is virtually quartzite. Microscopic examination of the gneiss indicates the presence of oligoclase, apatite, zircon, titanite, magnetite or ilmenite, epidote, and allanite. Individual layers range in thickness from less than an inch to about 4 feet; most are a few inches thick. Contacts between layers may be sharp or gradational. In a few places conformable beds, as much as 10 feet thick, of black medium-grained well-foliated hornblende gneiss lie in the biotite gneiss. These hornblendic rocks are comparatively rare in the mapped area and were not studied separately. Rocks of this kind are common in the gneiss outside the area mapped. Thin sills and dikes of aplite and of pegmatite are numerous.

The equigranular biotite gneiss, although probably not the most abundant type in the mapped area, is typical of the gneisses in eastern Vance County and western Warren County. These gneisses are regarded as having been a series of sediments, mainly sandstones and shales, that have been subjected to regional dynamic metamorphism. The hornblende gneiss may have been derived either from mafic sills, tuffs, or flows, or from impure dolomites. Within the mapped area the grade of metamorphism is rather low (biotite, or possibly, garnet grade), but some 30 miles farther southwest it reaches the kyanite-staurolite grade.

Porphyroblastic biotite gneiss seems to be the dominant type. It occurs throughout the mapped area, interlayered with other types. It is distinctly spotty or knotty because of abundant pink and white lenticular, roundish, or tabular feldspar grains within a matrix of wavy films of micas. These metacrysts average 0.1 to 0.2 inch in length, but some are nearly 1 inch long, and in many specimens they constitute about half the rock. They are subhedral to euhedral crystals of perthitic microcline, orthoclase, and oligoclase; most are simple twins. Myrmekitic intergrowth of quartz-oligoclase forms borders around, or penetrates as lobes into most of the potassic feldspar porphyroblasts. Some have been fractured and veined by quartz. The matrix of these rocks is the same as the equigranular gneisses except for the interruption of the foliation by partially cross cutting metacrysts. Interbedded in places with typical porphyroblastic rock are layers a few inches thick of sericite-chlorite phyllite. The contact of these two types may be very sharp, and in one place, a microcline "eye," which was about half an inch long, lay exactly on the contact, projecting equally into both rocks.

Coarse-grained, microcline augen gneiss occurs at many points in a zone about 3,000 feet wide that lies along the east side of the eastern phyllite strip. Also, within this zone are layers of phyllite and of the more usual biotite gneisses, but the coarse microcline-rich rock seems to predominate. The different varieties are complexly interlayered with one another. The rock is reddish, medium to coarse grained, and poorly foliated and is made up mainly of pink or red microcline with colorless or smoky quartz. Muscovite and biotite are minor constituents. The feldspars are ellipsoidal, ranging from about 0.1 to 1.0 inch in length. Even the larger feldspars form eyelike masses. Some bands are almost entirely feldspar, and the coarser feldspathic bands resemble the pegmatite described later. Quartz and mica form streaks between the feldspar augen, and quartz veinlets cut them. Contacts of the augen gneiss with bands of phyllite or biotite gneiss are parallel to the foliation. Some contacts are abrupt but many are gradational, and the adjacent rocks contain scattered microcline augen. The rock is brecciated in places.

The contact of the gneiss belt with the phyllite strip to its west is invariably gradational, regardless of the type of gneiss present. Bands a few feet thick of both rocks alternate with one another in the contact zone. Structural attitudes of both types are the same where they are exposed in one outcrop or in nearby outcrops. At the best exposures, it may be seen that bands of gneiss and phyllite alternate with one another over a width across strike of a few tens of feet. The phyllite bands commonly include thin layers or lenses of coarse pink microcline, or contain scattered feldspar metacrysts that decrease in number away from the contact zone. These observations seem to the writer best interpreted as indicating original deposition of conformable sedimentary beds of contrasting initial composition.

Abrupt variations in thickness occur in the eastern phyllite strip. (See pl. 1, loc. 9; fig. 2.) At a locality 1.7 miles southwest of Bullocksville, Vance County, N.C., the outcrop width varies from about 500 to 1,300 feet within a strike distance of 2,000 feet. Structural attitudes of the gneiss and phyllite in this interval are uniformly similar. Along the strike on the eastern side of the strip, phyllite grades to porphyroblastic gneiss.

These spatial relations, coupled with interlayering of phyllite and gneiss and their petrographic similarities, are interpreted as indicating that some gneiss—possibly much of or all the porphyroblastic and microcline augen types—has been formed by metasomatism of

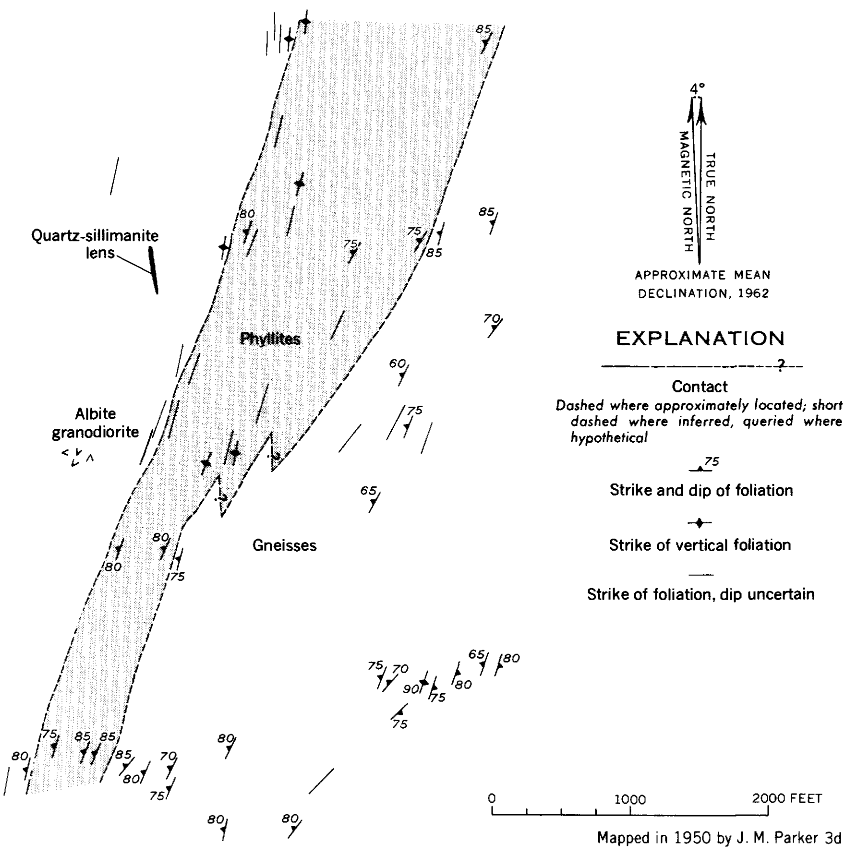

FIGURE 2.—Contacts between albite granodiorite and phyllite, and phyllite and gneiss, 1.7 miles southwest of Bullocksville, Vance County, N.C.

favorable beds of phyllite. During the metasomatism, recrystallization of some original constituents (probably supplemented by addition of potash and silica) has developed feldspar metacrysts in the metasedimentary rocks. The coarse microcline augen gneiss, because of its resemblance to the local pegmatites, seems especially likely to be an injection gneiss.

It is conceivable, of course, that a disconformity existed between the gneiss and the phyllite, with similar sediments below and above that surface. Such a hypothetical erosion surface could well be masked by later metamorphism, as well as by being now poorly exposed. The gneiss is more coarsely recrystallized than the phyllites, and more greatly altered; elsewhere in the belt, as near Raleigh, N.C., the gneiss has reached the kyanite grade of metamorphism; thus, it is likely to be a more deep-seated rock. Consequently, the gneisses are tentatively considered to be older than most of the phyllites and to originally have underlain them. It is also conceivable that the gneisses may be part of a metamorphic aureole surrounding the monazite-bearing granite some 5 miles to the east (Mertie, 1953, p. 26), and the western boundary of the aureole is seen as the contact between phyllite and gneiss in the eastern part of the Hamme district. Fieldwork toward the east has not been done, but it is recognized that the nature of the contact has regional geologic significance.

The total stratigraphic thickness of the gneisses is most uncertain. Only a part of the width of this belt was mapped in this district, and the extent of isoclinal folding is conjectural. The thickness is likely to total a good many thousand feet.

The gneisses may well be correlative with gneisses mapped by Laney (1917, pl. 1) along the western edge of the Virgilina district. Laney (1917, p. 18) believed that the latter were separated from the volcanosedimentary group by an unconformity but stated that the geologic relation is not definitely known. No evidence for the unconformity has been found in this work.

SERICITE-CHLORITE PHYLLITES

A great series of sericite-chlorite phyllites forms the walls of the district's central mass of albite granodiorite (pl. 1) and extends beyond its northern end. Along the east side the phyllite strip ranges in width from 450 to at least 3,500 feet; to the northwest in places it is as little as 300 feet, and on the west in places it is more than 11,000 feet in outcrop width. The western 3 miles of the reconnaissance mapping strip, which are adjacent to the Virgilina area (see pl. 2), are likewise underlain by phyllites. These are continuous westward with similar rocks, the Goshen schist and Hyco quartz porphyry of Laney (1917, pl. 1), which are exposed for a width of almost 3 miles beyond. Quartzite and metaconglomerate are interbedded with the phyllites, and the whole series is regarded by the writer as dominantly sedimentary in origin.

Typical sericite-chlorite phyllite is gray, buff, or greenish and very fine grained and well foliated. It splits readily into slabs that have smooth, flat to wavy surfaces and that, in fresh or little-weathered rock, appear distinctly lustrous or silky. Weathering dulls the luster and stains the rock yellow brown with limonite. Much of the rock shows distinct even bedding or fine lamination that, with very few observed exceptions (considered under "Structure"), exactly parallels the cleavage. The proportions of sericite and chlorite vary abruptly from layer to layer, so that very light gray, waxy sericite phyllite may be in sharp contact with green chlorite phyllite. Most rock appears to contain both sericite and chlorite. Graded bedding was not detected. Very small quartz grains are thickly scattered through the micaceous groundmass of much of this rock. Small feldspar grains, which are largely weathered to clay, are commonly observed. Grains and tiny octahedral crystals of martite are very abundant; in places, minute specks of this mineral are so thickly disseminated that the rock resembles graphitic schist. Much phyllite contains conspicuous, round to lenticular grains of white or bluish quartz that are 1 to 3 mm long. The foliation is partly interrupted by these larger grains and in part divided to pass around them. At a locality in Virginia (2 miles N. 50° E. of loc. 3, pl. 1), in the northwestern belt, the phyllite contains a roundish lens that is 7 by 9 inches and consists of fine-grained massive quartz and epidote; the foliation, in part, is cross-cut by and in part wraps around the lens.

Microscopic examination of some typical phyllites shows that they consist mainly of minute sericite flakes and small angular quartz particles. Chlorite flakes and feldspar particles are also present, but they are generally less common. The grains have the tangential contacts of a typical detrital sediment, rather than the interlocking contacts of igneous texture, although the long dimensions of both mica flakes and elongate quartz chips are alined in parallel. Scattered epidote and martite grains are numerous. In a martite-rich rock, large grains of this mineral replace and include sericite and quartz of the matrix. Indistinct coarser or more micaceous layers may be observed. In one section they are at an angle of 30° to 35° to the foliation. Micaceous minerals predominate in some specimens and in others quartz predominates. A specimen that contains scattered large grains proved to contain angular to lenticular fragments of plagioclase (albite-oligoclase) and some quartz, which were embedded in the much finer typical phyllitic ground mass that swirled around and between the coarse particles. Veinlets of quartz extend through some fractured large grains. The texture indicates that these larger particles were primary detrital grains rather than secondary metacrysts.

Near the western contact of the central albite granodiorite (pl. 1, loc. 6), about half a mile southeast of Marrow Chapel, sericite-quartz phyllite contains radiating sheaves, rosettes, and "bow-tie" groups of chloritoid crystals, as well as numerous slender tourmaline prisms. Chlorite and epidote are noticeably absent. A few garnet metacrysts occur in phyllite 1 mile north of the tungsten mine; this locality is 1,200 feet west of the albite granodiorite and 500 feet west of a large diabase dike. In the eastern strip, near the belt of gneiss, phyllite commonly contains scattered metacrysts of feldspar, and in one locality hornblende prisms occur in chlorite-rich phyllite.

Interbedded with the easily cleaved, lighter phyllites are more massive, green, fine-grained layers that superficially resemble green-

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stone. These obviously contain much chlorite and epidote, and microscopic examination indicates that a great deal of quartz is also present as tiny irregular particles. Some of these rocks possess good lamination. They appear to be metasiltstones.

Interbedding of the various phyllites with one another and with greenstone is indicated by the section (table 1) measured at locality 8 near the southwest corner of plate 1. Locality 8 is in the greenstone map unit, about 3¾ miles west of Williamsboro.

TABLE 1.—*Section of interbedded greenstone and phyllite exposed in road cut 0.4 mile west of the boundary between Granville and Nance Counties, N.C.*

[Loc. 8, pl. 1. Horizontal section extends S. 71° W., and the strike and dip of beds range from N. 40° W., 84° W. at the east end to N. 26° E., 76° W. at the west end of the exposure]

West end	*Feet*		*Feet*
Sericite-chlorite phyllite	90	Sericite phyllite	21
Covered	51	Greenstone	14
Greenstone and chlorite phyllite	9	Sericite phyllite	2
Quartz-tourmaline vein	1	Greenstone	14
Chlorite phyllite	62	Sericite phyllite	19
Sericite-chlorite phyllite	12	Covered	44
Greenstone	10	Chlorite phyllite	9
Chlorite phyllite	33	Sericite phyllite	12
Sericite phyllite	9	Greenstone	7
Greenstone and chlorite phyllite	17	Covered	39
Covered	14	Greenstone	15
Greenstone and chlorite phyllite	118½	Sericite-chlorite phyllite	9
Quartz vein	1½	Greenstone	36
Greenstone and chlorite phyllite	29	Sericite phyllite	4
Sericite-chlorite phyllite	54	Greenstone	18
Greenstone	13	Sericite phyllite	2
Sericite phyllite	18	Greenstone	3
Greenstone	24	Sericite phyllite	6
Covered	54	Greenstone	27
		Sericite phyllite	41
		Total length of section	962.0
		East end.	

Quartzite is present in the phyllite belt at several points along opposite shores of Kerr Reservoir, within 1,000 feet northwest of the contact with albite granodiorite (pl. 1, loc. 3). Most of the rock is dark gray because of the presence of smoky quartz and of very fine grained magnetite. Some of the quartzite is rudely laminated by magnetite-rich streaks, but no crossbedding was observed. Similar rock was noted at several places in the narrow eastern phyllite belt. Some of this, however, is seen in thin section to have been a rather well sorted arkose.

Conglomerate (or breccia) phyllite occurs at a number of places along the Roanoke River (pl. 1, loc. 2) in the same part of the belt as quartzite. The bulk of this rock is identical with sericite-chlorite phyllite as already described, but in addition it contains rock fragments that in some outcrops compose nearly half the rock. These fragments range in shape from flat slabs to subspherical masses; even the slabs are subrounded in plan. The more rounded pebbles are as large as 1¼ by 2 by 4 inches and consist of gray tough cherty quartzite (or possibly vein quartz). The more common thin chips and plates are as much as 5 inches wide. They are light-gray or dark-bluish-gray aphanitic slaty rocks that are megascopically identical with the chlorite phyllite or sericite phyllite that occur elsewhere in the same belt. No fragments of massive, felsic or mafic, metavolcanic rocks, such as those that occur farther west in the district, were identified in the conglomeratic phase. The fragments lie parallel to bedding and to foliation, and their distribution affords no clue to the top of the sequence. No features were observed that show whether the phyllitic fragments were metamorphic rocks at the time of their deposition or whether cleavage was first imposed upon them at the time the matrix and whole series were metamorphosed. The latter view is regarded as more probable. If the apparent absence of metavolcanic fragments is real, it may signify that the phyllite series is older than the metavolcanic rocks. The same conclusion is reached from bedding-cleavage relations described in the section on "Structure."

For lack of exposures, the conglomeratic and quartzitic phases could not be traced as separate map units.

Although a considerable variety exists in this series mapped as sericite-chlorite phyllite, its outstanding characteristics are regarded as indicating it was originally detrital sediment. Some parts of it may well have been pyroclastic, and some lava flows may also have been included. The high content of mica and chlorite in the siltstones, as well as in the matrix of the conglomerates, seems to point to poor initial sorting of the sediment. The bulk of the series, thus, is one of the graywacke suite. The quartzites may represent local "cleaned graywackes." The arkosic varieties may reflect similar concentration in the more feldspathic beds through removal of finer matrix.

The original thickness of the series is conjectural. It is only a few hundred feet in outcrop width in some places but is believed by the writer to have been drastically thinned by transformation into gneiss on the east and into albite granodiorite in the center of the district. These possibilities are considered later. The extreme outcrop width (5 to 6 miles) of such rocks in the eastern Virgilina district and area immediately adjacent to the east (see pl. 2) is likely to have resulted from doubling or trebling through folding, although direct structural evidence of this was not obtained. A reasonable estimate of original stratigraphic thickness, then, might be about 10,000 feet.

GREENSTONE

Large areas are underlain by mafic extrusive rocks along the western and northwestern sides of the district, just west of the phyllite belt. More extensive mapping to the northwest would presumably show this to be a continuous belt (pl. 1). These rocks are mostly dark green, characterized by chlorite and epidote, and are grouped under the heading "Greenstone." Foliation is generally poor and is lacking in some black varieties. In others that are richer in chlorite, fairly good cleavage is developed; some may properly be named chlorite phyllite or greenschist.

The variety most commonly observed is metabasalt, which is nearly massive and shows only a slight tendency to cleavage. This rock is dark green or black and ranges in grain size from completely aphanitic to very fine grained. At places a few phenocrysts of white plagioclase or of hornblende may be seen. Microscopic examination shows an intergrowth of epidotized plagioclase, which is identified as labradorite where not too altered, hornblende, sericite, chlorite, magnetite, and locally biotite. Some of the hornblende was clearly derived by alteration of pyroxene.

Amygdaloidal phases are common at intervals through the series. Along the former bluffs south of the Roanoke River (pl. 1, loc. 1), now largely submerged, at least 1,800 feet of amygdaloid was exposed. The dark-green nearly aphanitic rock contains round and irregular masses, generally 0.1 to 0.3 inch thick, of quartz or epidote that fill former vesicles. A specimen from 2 miles east-northeast of Bullock contains calcite amygdules as much as 1 inch wide. Knotty outcrops of this rock are especially numerous near the eastern edge of the greenstone belt, which extends along the Granville-Vance County line in the western part of the district.

Interbedded with the more massive mafic volcanic rocks are layers of dark, chlorite-rich phyllite that may have been formed by metamorphism of andesitic tuff and tuffaceous breccia. These appear to be especially common in the southwestern part of the area of general mapping. (See pl. 1, loc. 8; fig. 2.) Some specimens have the mottled cleavage surfaces that commonly indicate a pyroclastic origin, and a few contain rock fragments. Others appear to be sheared metabasalt porphyry. Megascopically similar chlorite-rich phyllite, however, is commonly interbedded with the sericite-chlorite phyllites of the belt lying just to the east; thin sections of some such specimens show them to have been metasiltstones of the graywacke type. Consequently, the origin of many such well-foliated chlorite-rich layers is in doubt, and partly for this reason the boundary between the phyllite and greenstone belts has been a difficult one to draw with assurance.

Greenstone crops out in belts that are about 500 to some 7,000 feet wide. At the northwest edge of the map at a bend in the Roanoke River (pl. 1, loc. 1), amygdaloid that appears to be doubled around a plunging fold crops out over a width of about 1,800 feet and hence may be about 900 feet thick or less. The minimum thickness of the greenstone in the district, then, is likely to be about 500 feet, and the average may well be several times as much. Substantial and abrupt variations in thickness from place to place are to be expected in a sequence of lava flows.

METAFELSITES

Felsic volcanic rocks that have been little metamorphosed underlie much of the western part of the Hamme district (see pl. 1) and of the area between the Hamme and Virgilina districts (see pl. 2). These massive to poorly foliated rocks are aphanitic or very fine grained and range in color from nearly white through bluish grays to brown. A few varieties are almost black. Most are equigranular and so fine grained that no constituents are recognizable with hand lens. Some varieties of the felsic volcanic rocks, however, have small phenocrysts of feldspar, quartz, or hornblende. One medium-dark variety with a very fine grained groundmass encloses white plagioclase tablets that are as much as an inch long. Pyrite is fairly common. Indistinct banding, presumably due to laminar flow while the rock was partly crystallized, can be observed in some of the felsite. Small irregular spaces, possibly vesicles, are common.

Microscopic examination of a few varieties of metafelsite shows that they are composed mainly of sericite, chlorite, epidote, clinozoisite, quartz, and oligoclase. The plagioclase commonly contains many tiny inclusions of sericite and epidote. Potassium feldspar was not noted. One light-colored rock consisted almost wholly of albite microlites, irregular grains of epidote and quartz, a few albite phenocrysts, and veinlike lenticular areas filled by radiating groups of zoisite prisms. Veinlets of quartz, or of quartz and epidote, are common in most varieties; one nearly cryptocrystalline sericite-epidote-quartz rock was cut by a veinlet of epidote, titanite, chlorite, and quartz.

Most of these rocks appear to have been surface lava flows of dacite or of related rocks. A dark flinty variety may be metarhyolite, possibly devitrified obsidian (aporhyolite)[1] (Bascom, 1896, p. 38); however, a good many exposures show that the dark flinty rocks were intrusive and composed dikes cutting tuffs or flows. (See figs. 3, 4.)

Interbedded with, or intruded by, the more massive felsitic rocks are considerable thicknesses of moderately well foliated, phyllitic metatuff and tuffaceous breccia. The metatuff and tuffaceous breccia occur in the western part of the area shown on plate 1, espe-

[1] The "Geologic Map of Virginia" (Stose, 1928) shows large areas designated "aporhyolite" just north of the Hamme district and in the Virgilina district, but much if not most of this rock is well-foliated phyllite, almost certainly of sedimentary origin.

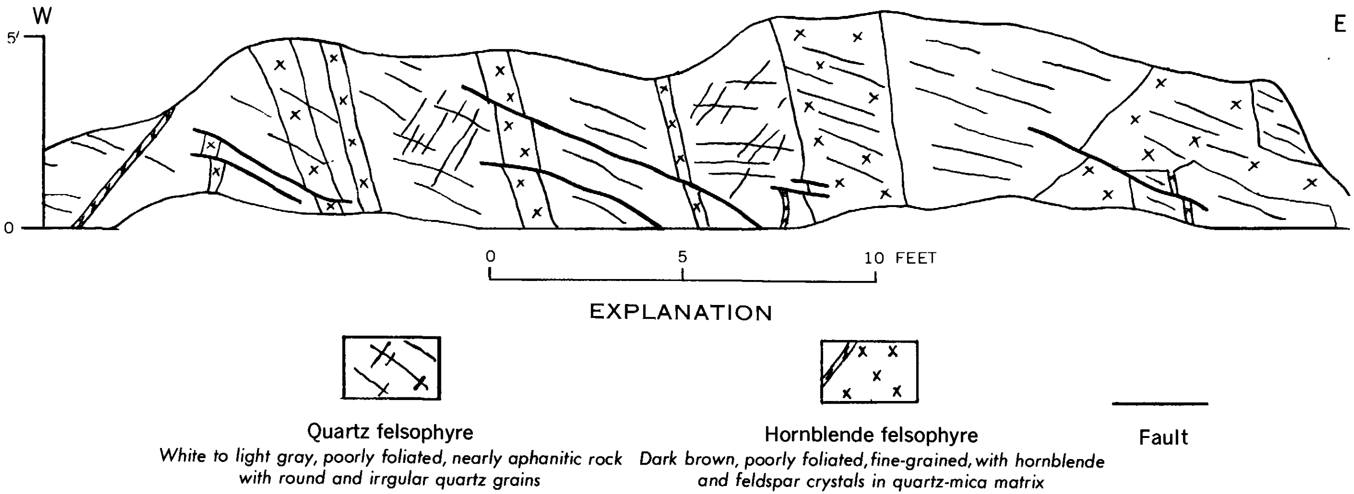

FIGURE 3.—Sketch of faulted and jointed dikes in road cut 0.8 mile east of Bullock, Granville County, N.C. East-west section slopes 35° S. Trace of fractures (N. 83°–87° W., 60°–70° N.) slopes gently to right; trace of foliation (N. 33°–45° E., 60°–80° NW.) slopes steeply to left.

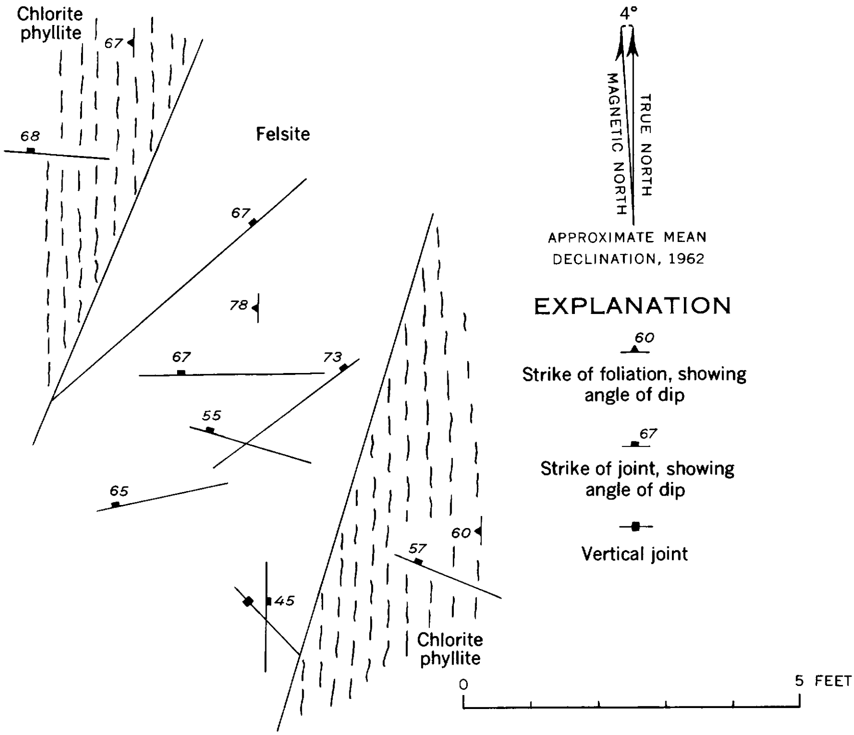

Figure 4.—Joint pattern in dike(?) of poorly foliated gray felsite cutting dark-brown chlorite phyllite (metatuff?); 1.0 mile N. 12½° W. of Bullock, Granville County, N.C.

cially just east of Bullock in Granville County, but they were observed at many points throughout the belt of felsic volcanic rocks. Exposures are too few to permit mapping them separately.

The probable pyroclastic nature of the phyllitic metatuff and tuffaceous breccia is indicated in hand specimen by mottled cleavage surfaces that resulted from lighter and darker flattened thin fragments, by vague roundish spots and irregular flat lenses of contrasting material, and by locally distinct angular rock fragments that are as much as an inch thick in finer grained matrix. The rocks are commonly bluish gray or slightly greenish and are usually too fine grained for megascopic mineral identification. The finer rocks are sericite-chlorite phyllites with wavy cleavage surfaces; the coarser ones are more massive and knobby in outcrop because of differing resistance to weathering of the various fragments and matrix.

Thin sections of two fine-grained metatuffs reveal in one rock a groundmass of almost cryptocrystalline massive quartz, plagioclase, epidote, and sericite, and in the other a groundmass of tiny sericite flakes alined in parallel. In the groundmass of both rocks are numerous euhedral laths and irregular grains of oligoclase and fewer grains of quartz and magnetite. Many of the grains have been fractured, the fragments displaced slightly, and the spaces between them filled with matrix material. Some of these rocks seem to have been little altered by metamorphism, hardly more than thoroughly consolidated.

The outcrop width of the principal area (pls. 1, 2) of metafelsite ranges from about 3,000 to 7,000 feet. The outcrop width is poorly known because the western contact of the metafelsite is not shown for much distance on plate 1; however, the dips are high, and these widths may approximate thicknesses. Whether the section is duplicated by isoclinal folding is not known. As illustrated in the generalized cross section (pl. 2), the thickness is about 3,700 feet; this is believed by the writer to represent the correct order of magnitude of the average thickness.

METABASALT

Black basaltic rocks that show little sign of alteration are common in the western part of the Hamme district near Bullock (pls. 1, 2) and between Bullock and the Virgilina district. They lie between two belts of metafelsites. This unit is differentiated from greenstone, with which it has much in common, because it has little or no foliation, is geographically separated, and is probably a somewhat younger group of rocks.

The characteristic rock is black to dark green and aphanitic or very fine grained. It is tough, brittle, and almost completely without cleavage. Outcrops are massive, so that orientation is commonly uncertain. Joints in 3 or 4 directions are usual. At Grassy Creek, dikes of basalt about 1 and 3 feet thick cut slightly coarser mafic rocks; these dikes have fairly distinct columnar joints.

Closely associated with the metabasalt is a porphyritic rock that differs only by having abundant phenocrysts, which may compose nearly half the rock. The phenocrysts consist of labradorite in narrow tabular or stubby crystals as much as one and a quarter inches long, or of aggregates of epidote or clinozoisite replacing plagioclase. Small irregular grains of titanite are very plentiful in at least one metabasalt porphyry 1½ miles north-northeast of Bullock.

Amygdaloidal phases similar to those in the greenstone are also fairly common in the metabasalt. The coarse clastic texture that was observed in some rocks is thought to indicate volcanic breccia. Green phyllitic layers probably were finer pyroclastics of andesitic composition. These rocks were not studied microscopically.

The metabasalt seems to vary considerably in thickness from place to place. Outcrops as mapped range in width from about 1,000 feet to 6,600 feet. Thickness determinations are uncertain because the orientation of the rock commonly cannot be measured with assurance. Computation of true thickness by using the scanty dip values available give amounts ranging from about 600 to 6,000 feet.

The metabasalts are clearly of volcanic origin, and flows appear to have been much more abundant than pyroclastic rocks.

CORRELATION WITH ROCKS OF THE VIRGILINA DISTRICT

Tentative correlation of the metamorphic rocks in the Virgilina and Hamme districts is based on three brief visits to the North Carolina part of the Virgilina district. The geologic map of the Virgilina district, taken from the report by Laney (1917, pl. 1), is a part of plate 2. All the rocks seen in the Virgilina area are like those mapped in the Hamme district. They are interbedded with one another in narrow bands; thus, Laney's map units are composites that are characterized by a predominance of one variety. Just how consistently this could be carried out through the district can not be judged, but at several of the points visited, the predominant rock differs from the descriptions given. The Aaron slate (Laney, 1917), in particular, seems to contain much rather massive rock like the metafelsites of the western Hamme district. Such rocks are not described in Laney's report.

Sericite-chlorite phyllites of the Hamme district include types corresponding to Laney's Aaron slate, Hyco quartz porphyry, and Goshen schist, as well as the schistose parts of the Virgilina greenstone. The Aaron slate is especially variable and is likely to have been formed from a sequence of fine to coarse clastic sediments resembling graywacke. Hyco quartz porphyry and Goshen schist differ little from each other and correspond to quartz-sericite phyllite and sericite phyllite of the Hamme district. Metafelsites of the Hamme district have no mapped counterpart in the Virgilina district, but such rocks were observed interbedded with Aaron slate at the type locality. Greenstone of the Hamme district corresponds with the more massive, porphyritic, and amygdaloidal parts of the Virgilina greenstone. Gneisses of the two districts were not compared. It is apparent, then, that different rock units were mapped in the two districts and that they are not directly equivalent.

The metamorphic rocks of the Virgilina district (excluding the gneisses) were interpreted by Laney (1917, p. 18–19) as a volcano-sedimentary series. The bulk was thought to have been composed of lava flows, tuffs, and volcanic breccias, largely of andesitic composition. Admixed with this was more or less landwaste, which was conceived to have consisted in part of normal weathering products but perhaps mainly of little-altered pyroclastic materials that were redeposited by streams soon after they were erupted. The result was a complex sequence varying considerably from place to place.

The same general stratigraphic picture seems applicable to the Hamme district, as far as the phyllites, greenstones, metafelsites, and metabasalts are concerned. The chief point of difference relates to the amount of pyroclastic material versus normal products of weathering. In the Hamme district, sediments of the graywacke suite with related variants are thought by the writer to be of major importance. Lava flows of felsite and basalt or andesite are thought to be abundant. Pyroclastic material is thought to be minor.

INTRUSIVE ROCKS

Intrusive rocks of both mafic and felsic composition occur throughout the district. The earliest appear to be bodies of hornblende gabbro that lie in the western part of the mapped area (pl. 2). Albite granodiorite underlies a very large central part of the district and a small area to the southwest. This granodiorite is included with the igneous rocks, although evidence is put forward to indicate that it may be granitized metamorphic rock rather than magmatic in origin. Aplite and pegmatite dikes and sills are closely related to the granodiorite. These mafic and felsic rocks are likely of Paleozoic age, perhaps mid-Paleozoic.

Cutting across all other rocks are dikes and sills of diabase and hypersthene tonalite. These are almost certainly of Late Triassic age.

HORNBLENDE GABBRO

Hornblende gabbro forms three mapped bodies in the western part of the Hamme district. Possibly related rocks occur as small unmapped masses at several localities farther east. The largest gabbro body is in the strip of reconnaissance mapping between the Hamme and Virgilina districts. (See pl. 2.) This was not studied in detail and may prove to be somewhat different from the others in that it is an intrusive complex rather than a single body. Hornblende-biotite granite or tonalite also occurs within this area but was not mapped separately. At one locality hornblende-biotite granite formed two gently dipping dikes 5 and 6 feet thick in the gabbro. Hornblende basalt dikes cut the gabbro near its northwestern margin. The metavolcanic rocks surrounding this mass on the west, north, and east generally dip towards it from east, north, and northwest, forming the Spewmarrow syncline, which is described later. The southern side of the gabbro was not mapped, but a traverse to the south of it indicates that it does not extend far in that direction; so, its outcrop area must be roughly circular. Its contacts were not observed; so, the form is not known. Dips in the wallrocks are mostly steep; thus, its shape is more likely to be inverted conical or cylindrical rather than basinlike (lopolithic).

An elongate body of hornblende gabbro that is about one-half mile wide is exposed some 2 miles to the northeast of Bullock (pl. 1). The body of gabbro extends 2 miles northward in North Carolina and bends abruptly northeastward near the State line. The northern part of this body is shown in the "Geologic Map of Virginia" (Stose, 1928) as Redoak granite, extending about 8½ miles north-northeastward. Definite contacts could be satisfactorily located at only five places, and outcrops are few; hence, the outlines of the body were drawn mainly from the distribution of soil and float.

Rounded exfoliated boulders of gabbro as large as 6 feet in diameter are abundant. Contacts, determinable on the east and west sides only, are approximately conformable, but the nature of the southern boundary is entirely conjectural. The rock is black to medium gray, and coarse to medium grained; it consists mainly of black hornblende and white feldspar. Hornblende composes an estimated 50 to 90 percent of the rock, the average being toward the lower limit. Microscopic examination indicates the presence of subhedral to euhedral labradorite that is generally altered in part to epidote, sericite, and chlorite, and in one specimen was seen to be riddled by a mineral tentatively identified as analcite. A little plagioclase shows definite zoning, but most grains have irregularly wavy extinction apparently owing to strain. Twinning is mostly irregular and diffuse. Most plagioclase individuals are cracked and have epidote and sericite in the fractures. Twin lamellae are commonly bent or slightly displaced. Hornblende occurs as irregular masses filling the spaces between plagioclase crystals. No augite was observed, but apatite prisms are abundant, especially as inclusions in hornblende, and much magnetite is present, in part filling cracks in shattered hornblende. At a locality near its center the gabbro contains several inclusions, a few feet thick, of decomposed foliated rock; here the gabbro is cut by granite dikelets, a thin quartz vein, and epidote-quartz veinlets.

A much smaller lens of similar coarse hornblende-plagioclase rock occupies an area of about 800 by 2,500 feet 3 miles farther south (pl. 1). This body is poorly exposed and was mapped almost wholly from float.

The gabbro is older than some of the granite, as shown by the presence of fairly fine grained granitic dikes in the two largest gabbro bodies. Within the outcrop area of the large gabbro in the Spewmarrow syncline, granite float is abundant in places but not in the surrounding country rock. Inasmuch as this area was mapped only by reconnaissance, the age relations are uncertain; but the similar distribution of the two rocks may indicate the granite is a differentiate of the gabbro, presumably a late phase.

The relation of the granite associated with gabbro and the albite granodiorite that underlies the middle of the district remains problematical. Neither continuity nor petrographic identity has been established. The albite granodiorite is tentatively regarded as the product of granitization and hence perhaps unrelated genetically to the granite in gabbro. Nevertheless, the gabbro is arbitrarily placed as the oldest igneous rock because some granite is younger, but it must be understood that their relative ages are not definitely established.

Hornblende-rich igneous rocks also occur in the central and eastern parts of the district, mostly in the central albite granodiorite within about half a mile of its western margin, but one locality is in the eastern phyllite strip just south of the area mapped in detail. Espenshade (1947, p. 5) reported two occurrences within the belt of tungsten mineralization. They form isolated exposures or float that could not be traced. Contacts were not observed. The sizes of these bodies must be small, but their shapes and relations to surrounding rocks are not known. They are fine to medium grained and composed mostly of hornblende prisms in white plagioclase. Some have appreciable quartz. These rocks are similar to the gabbro but less mafic. They have not been much studied but may be diorite and quartz diorite. These hornblendic rocks seem to be closely associated with albite granodiorite, in a manner resembling the association of hornblende granite or tonalite with gabbro in the large body in the Spewmarrow syncline. These rocks are tentatively regarded as local phases of the albite granodiorite.

Dikelike bodies of very fine grained dark-gray to greenish-black rock were noted at two localities in the central body of albite granodiorite, about a mile southwest of Townsville. These narrow tabular masses are in sharp contact with the granodorite and appear to be intrusive into it. They consist mostly of hornblende and epidote subhedral grains in a finer matrix of plagioclase (andesine), chlorite, biotite, muscovite, quartz, and epidote. Although greatly altered, they appear to have been fairly mafic porphyritic hypabyssal rocks. They seem to have been intrusive into the albite granodiorite, but they may have intruded the antecedent rocks that were later granitized, in which case they are now relict inclusions. Their age and origin remain in question.

ALBITE GRANODIORITE

The dominant rock in the Hamme district is albite granodorite. It forms a large mass in the center of the mapped area (pl. 1) and a much smaller one near the southwest corner. The central body is a great lens-shaped mass trending north-northeast that narrows abruptly to a point at the north end and thins southward also, but opens out again to the west beyond the limits of mapping. Its maximum width is nearly 7 miles, and its length more than 28 miles. The smaller body is similarly lenticular and is about 0.5 by 1.5 miles in size.

The albite granodiorite is medium to coarse grained and is typically massive; some is porphyritic. The rock is generally dark gray, although in places it is somewhat greenish and a little is light pinkish brown. Biotite, blue or gray quartz, and white plagioclase are identifiable with hand lens; large rectangular microcline crystals appear in places. Microscopic examination shows that albite (about Ab_{90}) generally composes 50 percent or more of the granite. Microcline and perthite locally predominate over the albite; generally they average about 20 percent of the rock. Feldspars mostly occur in large euhedral to subhedral grains. Albite invariably is crowded with a myriad of tiny sericite and epidote or clinozoisite inclusions, but the rims are relatively free of inclusions. Sericite also lies along feldspar boundaries, and one flake may project into adjacent feldspars. Potassium feldspar has few or no inclusions; it appears to replace plagioclase. Many feldspar grains are shattered or show strained twinning bands. Quartz ordinarily is abundant, forming 20 to 30 percent of the rock, and wavy extinction indicates that much of it is strained. Quartz crosscuts both feldspars and biotite. Biotite flakes and aggregates lie mainly between and alongside feldspar crystals, with a few smaller ones included in albite. Biotite and chlorite are closely associated with interpenetrating boundaries, but it is uncertain which is the earlier formed mineral. They make up 4 to 5 percent of the rock. Common accessories include titanite, zircon, apatite, magnetite, ilmenite, leucoxene, and pyrite. The accessory minerals compose about 1 percent of the rock. Lighter colored albite granodiorite containing muscovite and colorless quartz and having little biotite was observed at various places throughout the mass but was not mapped separately. The average composition of the rock is about 25 percent quartz, 20 percent microcline and perthite, 50 percent plagioclase, and 5 percent of mafic and accessory minerals. The rock is referred to as albite granodiorite because of the sodic composition of the plagioclase.

The wallrocks on all sides of the central mass of albite granodiorite belong to the sericite-chlorite phyllite series of metasedimentary rocks. The overall form of the albite granodiorite is conformable to the regional structure. The foliation of the phyllite in general conforms with the trend of the contact; this is especially true of the smoothly sinuous west contact. The most notable of several exceptions is the stretch of contact that begins about 2 miles north of the Island Creek Dam and continues northeastward for about 1¼ miles. (See pl. 1, loc. 5, and fig. 5.) In this interval, the west

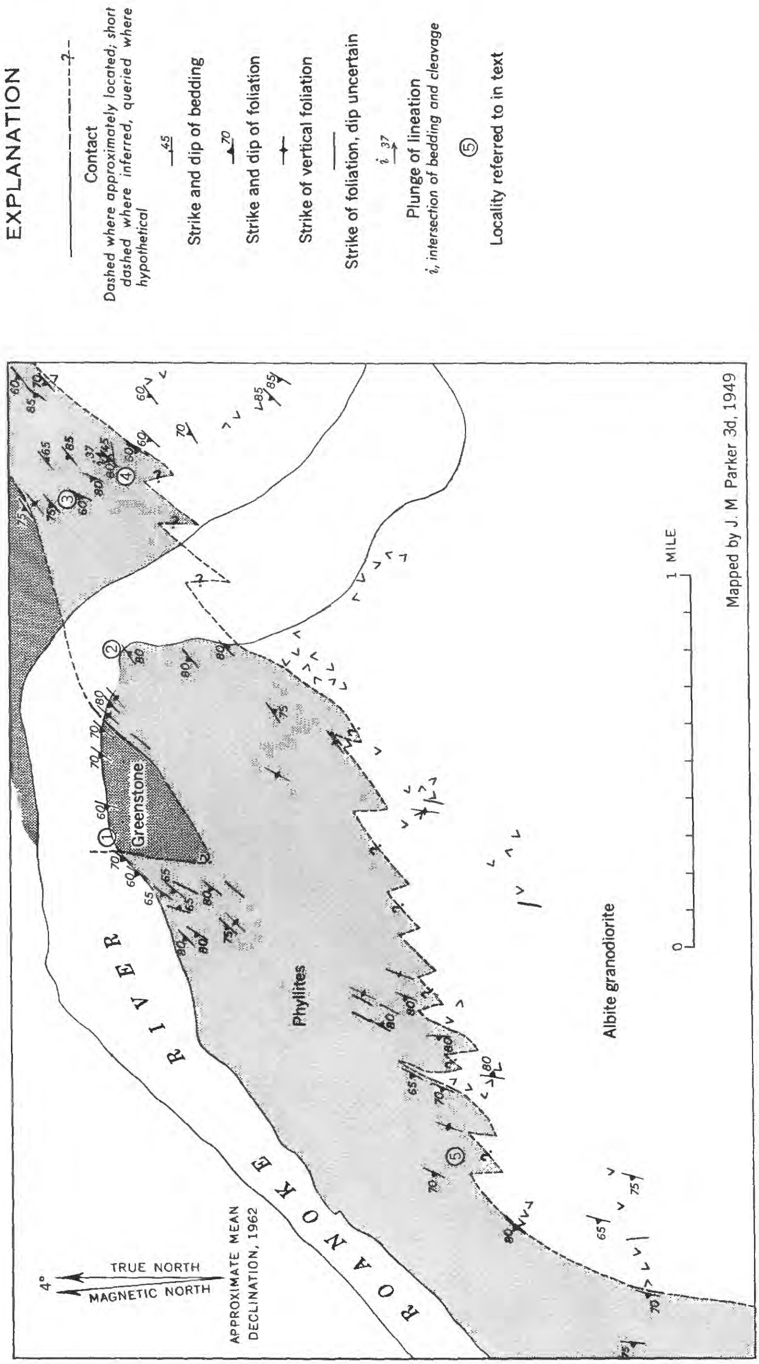

FIGURE 5.—Western contact between albite granodiorite and phyllite near Roanoke River, 6 miles north of Townsville, Mecklenburg County, Va.

contact of the albite granodiorite bends sharply from N. 10° E. to N. 70° E., whereas the phyllites swing only to N. 30°–40° E. The contact north of the Roanoke River bends back more to the north and again parallels the foliation. In the area of the abrupt bend (loc. 5), for a distance of about half a mile, strips of phyllite alternate across strike with albite granodiorite. The contact is masked for the next three-quarters of a mile eastward by soil and sediment. It is fixed as to location and trend by exposures at three places near and on both sides of the river. These short stretches of contact are not lined up with the trend of foliation and contact but have en echelon positions staggered to the right. Because albite granodiorite and phyllite were observed to interfinger at several places near locality 5 on plate 1, the contact in this whole 3-mile stretch has been drawn as a series of zigzags. This saw-toothed form is in part hypothetical in detail as regards exact location, size, and form of the "teeth," but it has seemed the most reasonable solution of the observed spatial and structural relations. About half a dozen other places may be noted (pl. 1) where the contact of the central albite granodiorite was observed to make small zigzags.

A consideration of potential importance in this matter is the possibility that the greenstone that lies west of the phyllite and south of the State line may be continuous with that near the Roanoke River at locality 1 (pl. 1) and to the northeast. Should further mapping show that these are parts of one rock unit, then the abrupt change in trend of the contact of the albite granodiorite may be related to minor folds in the wallrocks similar to the syncline in the greenstone between localities 1 and 2. Because the greenstone in North Carolina thins to the north and is somewhat different in character from the greenstone at locality 1, some doubt is cast on this speculation. The greenstone at locality 1, however, appears to be folded into a northeastward-plunging syncline, and the shoulder of albite granodiorite south of that locality might be inferred to be emerging along the keel of the syncline. In any case, albite granodiorite alternates across strike with phyllite near locality 5, and the phyllite strikes directly toward the granodiorite. As a result of this crosscutting of the contact, the southwestward continuation of a thickness of some 2,000 feet or more of phyllite (measured perpendicularly to bedding and cleavage) north of the contact seems to have been lost to albite granodiorite. In the writer's opinion this suggests that some phyllite may have been transformed to albite granodiorite.

This discordant stretch of contact might perhaps be due to faulting, but there seems to be no other evidence of such movement. The east side of the albite granodiorite shows no comparable offset. Mapping has not extended to the west in Virginia far enough to indicate whether other contacts there are displaced. The possibility is not considered to be strong.

The small body of albite granodiorite near the southwest corner of the area mapped in detail has the same saw-toothed boundaries, especially at the north and south ends. Exposures of granodorite and phyllite with some greenstone alternate across strike, so that interfingering of granodiorite with its wallrocks is quite clear. Here again, the details of the exact form and location of the contact are not fully exposed, so that the contact as drawn is generalized.

The contact of the albite granodiorite at many places can be seen to be gradational. Well-exposed sections reveal alternating strips of phyllite and bands of granodiorite—for example, at a point about half a mile southeast of Marrow Chapel (table 2). The phyllite strips are a few inches to some 50 feet thick. The width of the transitional zone is 50 to several hundred feet. Within this zone much of the phyllite contains conspicuous lenticular quartz grains and, locally, feldspar crystals that are lacking elsewhere. At a locality on the east contact, half a mile south of the State line and in a zone about a hundred yards across, knotty phyllite containing roundish lenticular grains of blue quartz (0.1 inch long) grades westward, by increase of quartz and feldspar grains, through coarser porphyroblastic gneiss into gneissic granodiorite and finally into massive albite granodorite. Although the granodiorite is typically massive, much rock near the borders and near inclusions is highly gneissic. Distinct foliation may be observed as much as half a mile or more from the contacts, although massive rock intervenes. The foliation results from films and irregular streaky aggregates of small biotite flakes in roughly parallel position and, in part, from alinement of lenticular to rectangular feldspar grains. Gneissic granodiorite also generally contains strips of porphyroblastic phyl-

TABLE 2.—*Section of albite granodiorite with steeply dipping inclusions of locally porphyroblastic phyllite exposed in roadcut 0.6 mile southeast of Marrow Chapel, Vance County, N.C., near the west border of the albite granodiorite pluton*

[*Horizontal section extends N. 76° W.*]

	Feet
West end.	
Sericite phyllite	5.0
Gneissic albite granodiorite	17.0
Covered	15.0
Greenstone	16.0
Albite granodiorite	29.0
Aplite	.6
Chlorite phyllite	.9
Albite granodiorite	2.0
Chlorite phyllite	.5
Albite granodiorite	10.5
Chlorite phyllite	2.2
Albite granodiorite	3.3
Aplite	.5
Albite granodiorite	6.0
Chlorite phyllite	2.0
Albite granodiorite	21.0
Chlorite phyllite	5.5
Albite granodiorite	4.0
Chlorite phyllite	1.2
Albite granodiorite	18.3
Sericite phyllite	.5
Albite granodiorite	15.0
Chlorite phyllite	5.5
Albite granodiorite	18.5
Total length of section	200.0
East end.	

lite that are as much as 25 feet thick. Even in the middle of the granodiorite (pl. 1) there are inclusions of phyllite and of gneiss. Albite granodiorite grades into some inclusions and with others has sharp contacts (fig. 6).

A zone of schistose rock that is 50 to 100 feet wide is described by Espenshade (1947, p. 6 and pl. 2) in the albite granodiorite near its western contact, where the richest huebnerite veins occur. The zone was traced from the contact more than 2 miles in a N. 35° E. direction into the albite granodiorite with the aid of numerous trenches and bore holes. It contains sericitic schist, sericitized schistose granodiorite, and moderately sheared granodiorite and was interpreted as a shear zone. The conspicuous float in this zone is mainly reddish, iron-stained schistose rock composed mostly of sericite with lenticles of blue quartz. This was regarded by White (1945, p. 98–99) as "an altered phase of the schist * * * produced by mobile emanations from the granite." Espenshade (1947, p. 5), on the other hand, considered it to be extremely sheared and altered granite, a view also held by the mine operators (Sweet, 1954, p. 82).

Thin sections of several coarser grained rocks from this zone show definite cataclastic structures. The larger plagioclase grains are fractured, and the pieces offset or rotated slightly; strain shadows and bent twinning lamellae are common. Though local intense deformation in this zone is indisputable, it is doubted that the schistose (actually phyllitic) rock is mylonite or phyllonite resulting from retrogressive, dynamic metamorphism, for characteristic rigid parallelism of shear banding, the nearly complete crushing to uniform fine grain, flaser structure, and relict higher temperature minerals are all lacking. The more schistose parts appear to be residual patches that are interrupted by the larger grains, as well as traversed by coarser micaceous streaks which may represent shears. In a specimen with especially good foliation, the larger grains show little deformation. Many larger feldspar crystals have straight margins that abruptly crosscut the foliation of the matrix, a form suggesting they are later porphyroblasts rather than porphyroclasts remnant from a coarse granodiorite. Quartz also forms lenticular and irregular patches or grains, as well as veinlets, that transect the finer foliated micaceous matrix. The presence of calcite, fluorite, and pyrite in some of these rocks indicates hydrothermal alteration. The fine-grained phyllitic rocks from this zone that lack large feldspar or quartz grains are indistinguishable from the phyllites in the belt west of the albite granodorite. Thin sections of three specimens from the eastern contact zone also show shattered, displaced, and strained feldspars. They were taken from the east-

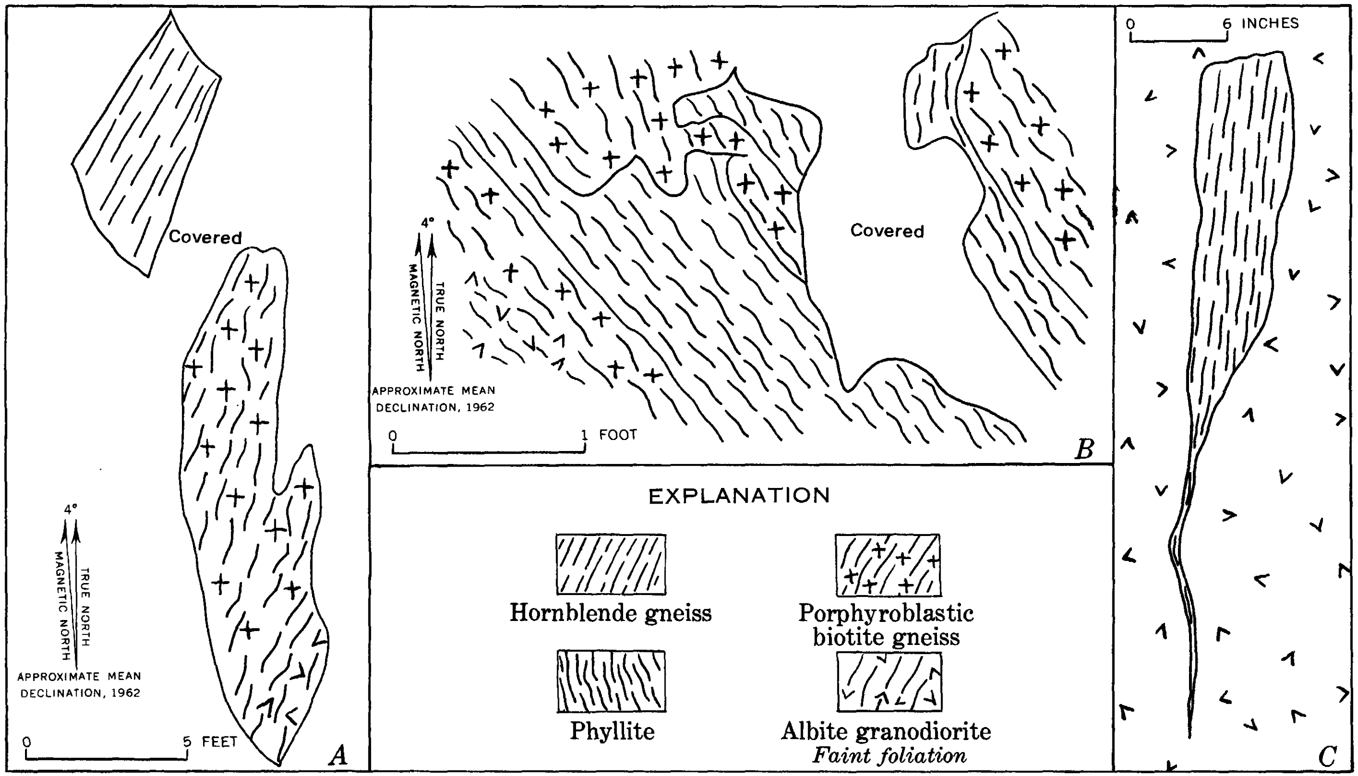

Figure 6.—Sketch maps of inclusions in albite granodiorite, Vance County, N.C., and Mecklenburg County, Va. *A*, Locality 9, Vance County, N.C., 0.75 mile N. 28° E. of Townsville; *B*, Locality 10, Vance County, N.C., 2.3 miles S. 20° W. of Townsville; *C*, Kimball vein, Mecklenburg County, Va., 4.5 miles north-northwest of Townsville. View looking N. 10° E. at vertical section of phyllite inclusion in albite granodiorite.

ern phyllite strip, from porphyroblastic gneiss just east of this phyllite, and from gneissic granodiorite just west of it. Although considerable movement seems to have occurred in this belt, the phyllite is believed by the writer not to have been formed by retrogressive metamorphism along a "shear zone."

Rocks exactly like those in this "shear zone" have been observed in the phyllite series more than a mile west of the albite granodiorite, in the narrow eastern phyllite strip, and as diversely oriented inclusions scattered through the mass of granodiorite (pl. 1), although no other comparably long phyllite belts in granodiorite were detected. Because of the field evidence that rocks of the type in question occur in positions where they could not have been formed by shearing of the albite granodiorite, coupled with petrographic observations interpreted as indicating that the fine-grained, schistose parts of the rock are residual rather than secondary, the "shear zone" extending through the mining area is interpreted by the present writer as a great slab of older sericite-chlorite phyllite included in the albite granodiorite and modified by injection and recrystallization. The cataclastic features of the rock are presumed to have resulted from localization of tectonic movement along this slab, rather than in the stronger granodiorite, at a period related to the deposition or alteration of the quartz-huebnerite veins.

A peculiar poorly foliated sericitic rock somewhat resembling the "shear zone" rock forms abundant float in a belt within the albite granodiorite just east of Little Island Creek. This belt is about a mile wide and lies about a mile east of the west contact of the granodiorite, extending southward about 4 miles from the State line. Its nature is poorly understood, as only two exposures were found. The rock is reddish brown or greenish gray and is medium to fine grained and rudely foliated or almost massive. It consists largely of sericite and contains much fine quartz. Roundish lenticles of blue or gray quartz about 0.05 inch long characteristically form up to nearly half of the rock, although in some specimens these lenticles are almost lacking. Subhedral plagioclase is abundant at a few localities. Veins and irregular masses of quartz are common in it. Microscopic examination indicates that this rock is composed of very fine grained sericite-quartz patches that have moderately good foliation, are now diversely oriented, and are interrupted and displaced by crosscutting coarse quartz grains and irregular veinlets. The mica is in larger flakes near the coarse quartz. Magnetite or ilmenite, leucoxene, hematite, and limonite are common throughout the rock, and a few zircon grains occur mainly in the fine-grained sericitic patches. An unidentified pale-yellowish-brown isotropic mineral (index moderately above balsam) forms roundish to irregular areas associated with opaque minerals and penetrating both sericitic patches and coarse quartz. This rock is believed by the writer to have been a poorly foliated sericite phyllite—derived perhaps from ferruginous silty shale—that has been modified by addition of quartz. The masses of unknown shape that it constitutes would thus be interpreted as inclusions in the albite granodiorite. Its character and origin are presumed to have been similar to those of the schistose "shear zone" rock just to the west, although the degree of alteration is greater.

Albite granodiorite is cut by dikes of aplite, pegmatite, tonalite, and diabase. Veins of quartz are common, including some very large ones, and veinlets of epidote or quartz-epidote are rather numerous. The albite granodiorite also contains an unusual siliceous belt, exposures of which are called Devils Backbone, about 2 miles south-southwest of Townsville, and a smaller sillimanite-bearing siliceous body about 3½ miles east-northeast of Williamsboro; these are described later.

ORIGIN OF ALBITE GRANODIORITE

The origin of the albite granodiorite is uncertain. Some of its features seem better accounted for by magmatic, intrusive processes, while others appear to suggest that a metamorphic process of granitization may have been responsible. Lack of well-exposed contacts is especially hampering in reaching a firm conclusion as to origin. In addition, further petrographic evidence is needed, especially regarding the accessory minerals and the structural patterns. In the following section, various features that may bear on the matter are discussed. The greater weight of evidence appears to the writer to favor an origin by transformation of older metamorphic rocks, chiefly sericite-chlorite phyllites of sedimentary derivation, but the question must be regarded as open.

1. Along the northwest contact (pl. 1, loc. 5) a thickness of some 2,000 feet of metamorphic rocks, mainly phyllites, trend southwestward directly into, and interfinger with, albite granodiorite as was described earlier. Tabular bodies of albite granodiorite and of phyllite alternate across strike at many places near this contact. The ends of these bodies are nowhere exposed; it is not known whether they grade strikewise into albite granodiorite or whether they end abruptly. Foliation in the granodiorite near this discordant contact is parallel to that of the phyllites forming the wall. Stoping of very jagged blocks of wallrock might explain the saw-tooth, discordant contact but would be unlikely to account for the parallelism of foliation on both sides. Faulting could cause the discordant contact but could not explain the interbanding of phyllite and albite granodiorite. There is no known sup-

porting evidence for such a fault, but of course, it may nevertheless exist. The possibility that this bend in the contact of the albite granodiorite is related to folds of the wallrocks has already been considered.

The same pattern of long narrow bodies of albite granodiorite and phyllite or gneiss alternating with one another is observed along the contacts in the area of reconnaissance mapping between Oxford and Henderson (pl. 2), where the south end of the pluton opens out westward. Here also foliation in the albite granodiorite and wallrocks remains parallel across discordant contacts.

2. Foliation in the marginal parts of the albite granodiorite corresponds in position to wallrock structure even where the contact is discordant. If the granodiorite were formed by upward flow of partly crystallized magma one would expect to find planar flow structure paralleling the walls. Thus, on the east and west sides of the pluton the foliation would parallel the cleavage of phyllites—as it does—but along the northwest side where the contact is discordant, the planar flow structure should lie at high angles to the trend of phyllite. On the contrary, at such places the foliation in the albite granodiorite as well as in the walls is discordant with the contact. This is invariable also at the south end of the albite granodiorite body between Henderson and Oxford (pl. 2).

Near the middle of the pluton, in most places, the foliation retains steep dips and the regional strike. This might reflect upward magma movement in a lenticular body. The attitude of mineral lineation here, unfortunately, is not known. Magmatic plutons commonly are massive near their centers, or have an arch or dome of flow layers and flow lines over their tops, rather than near-vertical foliation parallel to their length in the central region. Perhaps the latter condition does exist at very low levels in an elongate intrusive body, but the numerous inclusions and the low-temperature mineral assemblages that exist here contradict a supposition of very deep seated conditions. Consequently, because the foliation of the albite granodiorite shows such close conformity with that of the wallrocks, it is more likely to be a relict structure than a primary magmatic one, inasmuch as the latter is ordinarily related to the contacts rather than to wallrock structures.

3. Conformable contacts are everywhere gradational. This transition from phyllite to albite granodiorite occurs in part by interlayering of the two rocks and in part by increasing development of quartz and feldspar metacrysts in phyllite nearer the granodiorite. Some of the phyllite inclusions are little or

not at all altered, but most of them are more or less porphyroblastic and coarsened in grain. The contact zones contain much gneissic rock like the porphyroblastic gneiss of the eastern side of the district, which also grades into phyllite. Such gradational contacts, of course, may be found with intrusive rocks attributed to magmatic origin, but they are characteristic of metasomatic granites. Absence of sharp, discordant contacts, a feature normal to magmatic intrusive rocks, is apparently general in this district.

4. The overall shape and orientation of the albite granodiorite bodies are conformable to regional structure, but on the northwest side of the central mass of granodiorite the wallrocks bend around the pluton in such a way as to suggest that some room for the albite granodiorite was made by forcing the wallrocks apart. This fact favors a magmatic origin. It is possible, however, that metasomatic recrystallization might involve enough increasse in volume to account for the observed outward bowing of wallrocks. No quantitative data are available, however, to indicate whether the suggested transformation is likely to have occurred in a closed or an open chemical system.

   Structures around the small body of albite granodiorite near the southwest corner of plate 1 are not distorted around it. The granodiorite seems to replace areally the rocks in which it lies, and the same is true of the southern parts of the central mass between Henderson and Oxford (pl. 2). In general, the bodies of albite granodiorite seem to replace rather than displace the wallrocks, a condition favorable to the granitization hypothesis.

5. Rock inclusions in the albite granodiorite are mostly phyllites like those constituting the walls. This would be expected whether the origin of the rock was magmatic or metasomatic, and it is favorable to the latter explanation only in a permissive way. The inclusions are common even near the center of the pluton. This condition is to be expected if a sequence of interlayered rocks differing somewhat in composition had been granitized. The cores of magmatic bodies usually are relatively free of inclusions, except for linear groups along septa between units of a composite intrusive.

   Most of the inclusions in the albite granodiorite, both near and at a distance from the walls, strike north or north-northeast, parallel to wallrock structures. Near discordant stretches of the contact they are not parallel to the contact, as would be expected if they had been oriented by laminar flow of magma.

   Scattered through the central mass of albite granodiorite at about a dozen localities are phyllite inclusions that strike at angles of 30° to 60° from the regional trend. These exceptional orientations do not appear to be any more numerous per unit area than do similar diverse strikes in the wallrocks. They may reflect minor folds in the pregranitization rocks and, like the foliation, may be relict structures. Diversely oriented inclusions could also exist in a magmatic rock emplaced by stoping mainly, rather than by forcible intrusion. Finally, these inclusions may be the lower parts of roof pendants, whether the granodiorite be magmatic or metasomatic. In short, the inclusions probably can be adequately explained by either hypothesis.

The inclusions in the albite granodiorite, with the exception of one quartz-sillimanite mass that is described later, are rocks of low metamorphic grade. They are sericitic and chloritic phyllites like the wallrocks. Had such rocks been engulfed in magma they would be expected to have recrystallized so as to contain at least coarser muscovite, biotite, or hornblende, if not garnet and kyanite. The quartz-sillimanite rock is unique in the district, so far as is known, and is likely to be due to some highly localized condition.

6. Complex folding and faulting of the wallrocks are lacking. The district appears to be a homocline dipping steeply westward. Only a few small-scale folds and faults have been recognized, and these are not concentrated near the contacts. The walls are not closely crumpled as commonly is the case near magmatic plutons forcibly emplaced. The relatively undisturbed wallrock structure might be consonant with emplacement by passive stoping, but it also agrees well with granitization.
7. The huge barren quartz veins (described later), the siliceous belts, and the microcline-quartz pegmatites, as well as the tungsten deposits themselves, are ample indication of hydrothermal injection into both granitic and metamorphic areas. These injections could well be a consequence of the intrusion of magmatic granodiorite and may indeed postdate the granodiorite entirely. It is quite possible, though, that they represent the final phase of granitizing fluids, rather than emanations from magma.
8. The albite granodiorite varies in texture and composition abruptly from place to place. A great deal more petrographic work would be needed to demonstrate the areal distribution and extent of these differences, but the amount of mafic minerals especially varies a good deal. It is thought that these variations may reflect differences in the composition of earlier rocks that have been granitized. Outcrops are so small and

widely scattered that it may not be possible to prove or disprove this speculation, but in the southwestern part of the mapped area, where the bodies of albite granodiorite cut across the contacts of phyllite and greenstone, it may be feasible to correlate variations of the granodiorite with those of the walls. It seems likely that a magmatic rock would tend to be more homogeneous.

9. The albite granodiorite and its wallrocks belong to quite a low temperature mineral facies. The granodiorite contains sodic plagioclase (about Ab_{90}) with abundant sericite and epidote, and has relatively little microcline. Its mineral assemblage appears to be referable to the biotite-chlorite subfacies of the greenschist facies (Turner and Verhoogen, 1951, p. 466–469). The wallrocks belong to the next lower temperature assemblage—that is, the muscovite-chlorite subfacies of the greenschist facies (Turner and Verhoogen, 1951, p. 469–471). Chloritoid also occurs very locally in the wallrocks, but this mineral is stable in the muscovite-chlorite subfacies as well as in the albite-epidote-amphibolite facies, where it becomes an index mineral (Turner and Verhoogen, 1951, p. 460).

Most rocks attributed to granitization occur in terranes of high metamorphic grade. Instances of granitization at relatively low temperatures, however, are described by Misch (1949, p. 383–392) in China and are discussed by Ramberg (1952, p. 243). The mineral facies represented seem to be the lower part of the albite-epidote-amphibolite facies, which is a little higher temperature than the Hamme district granodiorite assemblage. The facies of the albite granodiorite of the Hamme district is consistent with its wallrocks, however, on the supposition that the granodiorite is the local culmination of metamorphism.

If the albite granodiorite had been formed from magma, the wallrocks should have undergone contact alteration that would have placed them in a much higher temperature mineral facies than they are now. Lack of such high-temperature contact effects is striking. If it is argued that the albite granodiorite was originally a magmatic granodiorite (Espenshade, 1947, p. 4) in which more calcic plagioclase has been altered to albite plus epidote, then it must be supposed that retrogressive metamorphism has also altered the wallrocks to a consistent lower grade, obliterating all trace of the earlier contact effects. That this degradation could have operated uniformly across the whole district, whether as a result of strong deformation or of hydrothermal activity, seems less likely than that progressive regional metamorphism of low intensity brought about the observed results in one step.

10. Textural features in the albite granodiorite seem more in keeping with an origin by recrystallization and metasomatism than by primary crystallization from magma with subsequent alteration. The overall texture appears to be crystalloblastic. The range of grain size is wide. Albite forms large subhedral to fairly euhedral crystals in crisscross positions. Smaller anhedral albite, microcline, quartz, mica, and epidote particles form a matrix. Boundaries of even the large tabular albite grains are sutured and irregular. Much of the microcline and almost all the coarser quartz grains cut into and across the outlines and twinning of grains of plagioclase, and must be not only late, but probably introduced.

Some albite granodiorite contains highly irregular patches of fine-grained muscovite, quartz, and feldspar having fairly good foliation. These look like remnants of sericite phyllite. They are abruptly interrupted by large ragged feldspar grains and fray out into these grains. In places, elongate sericite bands are abruptly pinched between two feldspar grains. Some smaller lenticular albite grains occur within the sericitic patches and extend with ragged borders into them; these have more sericite in their marginal than central areas. The sericitic patches definitely are not through-going streaks, as if developed along shears; on the contrary, they give the impression of being fragmentary remnants. In many places, fairly coarse muscovite and biotite occur abundantly in narrow bands along feldspar boundaries, but these surround individual grains and do not pass across the whole section or anastomose like shears.

The myriad inclusions of sericite and epidote in albite result in sieve or poikiloblastic structure, generally regarded as of metamorphic origin (Harker, 1932, p. 40). Espenshade (1947, p. 4) suggested that original calcic plagioclase has been transformed to albite and epidote, hence the inclusions in the albite would be interpreted as secondary alteration products. However, several observations seem to the writer to indicate that these mineral inclusions are relict from transformed phyllite. All albite grains have abundant sericite inclusions, but some grains of albite contain comparatively little epidote. Those with much epidote also have much sericite. Those albite crystals having fairly clear narrow rims have the same extinction position between crossed nicols throughout the whole grain—that is, the composition of the plagioclase is constant throughout. If the epidote was formed by breakdown of calcic feldspar with falling temperature, then the distribution of epidote might be expected to be more uniform, or the composition of the inclusion-free rims might be different from the central parts. If calcic plagioclase were altered hydrothermally, the change might be expected to proceed from the margins inward, so that the interiors might be clearer than the rims. No plagioclase crystals are zoned, nor are inclusions arranged in concentric pattern to reflect earlier zoning.

Microcline has almost no sericite inclusions and only a few very small specks of epidote. Preferential sericitization of the potassium feldspar seems to the writer to be more likely than the observed localization in sodic plagioclase. In addition, the total amount of fine muscovite in the rock, both in and between the albite grains, seems too much to be accounted for by secondary alteration. The presence of microcline perthite would seem to indicate a temperature originally in the magmatic range. The albite areas in the microcline perthite commonly are irregular in shape, crosscutting in position, and quite variable in amount from place to place in any one grain; this variation suggests that the perthitic structure was formed not by exsolution but rather by replacement.

These textural features suggest to the writer that phyllites were first transformed by growth of tabular albite prophyroblasts containing very numerous inclusions of relict sericite and epidote. Then, smaller anhedral microcline grains formed between, and partly replaced, albite crystals. The potassium feldspar grains are presumed by the writer to have formed by recrystallization of sericite. The grains of potassium feldspar incorporated the substance of the sericite within their boundaries, consequently they are virtually free of inclusions. Quartz replaced and veined both feldspars. Original chlorite in the phyllite became biotite flakes interstitial to the feldspars and quartz.

In summary, it appears to the writer that field observations and petrographic features are better accounted for by the hypothesis that the albite granodiorite is of metamorphic rather than magmatic origin. Further investigation or other lines of inquiry might indicate otherwise. Of interest in this connection are papers by Mertie (1953, p. 29; 1956, p. 1754–1755) in which many gneissic and granitic rocks of the southeastern Piedmont region are regarded as metamorphosed clastic sediments.

APLITE

Dikes of aplite are common throughout the central body of albite granodiorite, especially near its middle, and a few occur in the wall-rocks on the northwest side near the contact. Most dikes are only a few inches or feet thick, but those that are 10 to 40 feet thick are fairly numerous. Most are too small to show on the map and too poorly exposed to trace, but the outcrops of a few are indicated on plate 1. The largest dike, about 400 feet thick, was mapped for about 1 mile by Espenshade (1947, p. 5 and pls. 1, 2) near the center of the zone of tungsten mineralization, but it could not be traced east of Little Island Creek. The contacts of the dikes are invariably sharp. Dips are near vertical; strikes have a considerable range but trend toward N. 20°–25° E. and N. 20°–25° W. with a smaller number about N. 65° W. and N. 65° E. Small irregular areas of aplite that lack dike form were noted in the granodiorite at a few places. These have vague boundaries that are gradational into the albite granodiorite.

The aplites are barely phaneritic to very fine grained and range from light gray or buff to medium dark, greenish and brownish gray. Some have good foliation parallel to their walls, resulting from parallel orientation of mica-chlorite streaks and flakes and elongate subhedral feldspar grains. Epidote is abundant along the contact of at least one dike. They vary considerably in composition. Some lack microcline, and some lack plagioclase; the amount of quartz ranges from almost none to nearly half the rock. Quartz commonly replaces feldspar and forms veinlets. Specimens studied in thin sections include quartz-microcline-muscovite, quartz-microcline-albite-biotite, quartz-albite or oligoclase-biotite-muscovite, and oligoclase-quartz-biotite varieties. All these include much secondary epidote and chlorite. Common accessory minerals are magnetite, titanite, apatite, and zircon. One almost aphanitic rock contains as phenocrysts roundish quartz grains and hexagonal plates of muscovite.

No aplite dikes were observed that obliquely intersect other dikes or gneissic layering so that it might be determined whether they are dilation or replacement dikes. The foliation in the dikes is similar in character to that locally present in the albite granodiorite, but it parallels the dike walls, which commonly are at high angles to the foliation of the host. The sharp contacts and crosscutting position of boundaries and foliation of the dikes indicate that they probably were magmatic intrusive bodies, but a replacement origin has not been completely ruled out. In either case they are younger than the albite granodiorite. The vaguely bounded aplitic areas in the granodiorite are likely to be more finely recrystallized parts of the granodiorite rather than late intrusions.

PEGMATITE

Small bodies of pegmatite occur mainly in the gneiss belt, especially near its western side and in the most easterly part mapped. They are commonly present also in the eastern half of the central mass of albite granodiorite, and in very small amounts near its western border. This rock is thus noticeably localized in a north-northeast-trending belt extending about 3 miles west and 4 (or more) miles east of the narrow eastern phyllite strip, and is confined to areas of granodiorite or gneiss.

In the gneiss belt, pegmatite forms thin sills which, though conformable as a whole, commonly have contacts that cross the foliation for a few inches. Most sills range in thickness from less than 1 inch to 5 feet; one was about 20 feet thick. They are most abundant in the zone of microcline augen gneiss and in association with porphyroblastic biotite gneiss. Most pegmatite is massive though some is rudely foliated. It consists mainly of reddish microcline masses as much as 1 inch thick and smaller gray or bluish quartz grains, with small amounts of white oligoclase in places. Muscovite and biotite are local minor constituents, and flakes of muscovite as much as 2 inches wide were noted. Well-foliated quartz-muscovite pegmatite with virtually no feldspar was noted at two places in the gneiss. Muscovite flakes as much as 1.5 by 2 inches in width make up about a fifth of the rock. It resembles the type referred to locally as "burr-rock" in the western North Carolina pegmatite districts.

Pegmatite dikes in albite granodiorite commonly are only a few inches thick. The maximum thickness observed was 4.5 feet. The contacts of the pegmatite dikes are sharp, and the shape is uniformly tabular. They are like those in the gneiss except that no quartz-muscovite pegmatite was observed. Rude graphic texture occurs in at least one dike, 2½ miles southeast of Townsville.

At the western edge of the central mass of albite granodiorite, Espenshade (1947, p. 5) reported a very small amount of quartz-feldspar pegmatite found in drill holes on the Morton 1 and Walker 3 veins.

Pegmatite is younger than gneiss and granodiorte, which it cuts, and is apparently younger than aplite also though no completely satisfactory observation on this point was made. The mineralogical similarity and the close association of pegmatite with microcline-bearing gneisses—the only rocks in the district having much of this mineral—lead to the speculation that injection of the pegmatite fluids may have been responsible for transforming some phyllitic rocks into gneisses.

DIABASE AND HYPERSTHENE TONALITE

Diabase, probably Triassic in age, and hypersthene tonalite that is closely associated spatially occur as dikes and sills along four northward-trending belts that are rather evenly spaced from east to west across the district. These have been traced mainly by means of the distribution of float and soil. Trains of brown exfoliated boulders a few inches to several feet in diameter and, more rarely, of massive fresh blocks as large as 10 by 15 feet, mark the outcrops of the dikes. In places the boulders are so abundant as to have impeded agriculture, so that narrow strips of woods and thickets have been left across cultivated ground. Where the dikes are crossed by moderate-sized streams, rocky outcrops may form cascades; but where they are crossed by large streams, they have been buried in flood-plain alluvium. The smallest streams commonly fail to uncover the dikes. Actual contacts of the dikes with wallrocks are exposed only in a very few excavations. Although diabase is generally enough exposed to be traced along strike—the only rock other than quartz veins and siliceous belts for which this has been possible—the outcrop along many uplands is concealed by thick soil with dense vegetation or by high-level alluvium. In one excavation, a diabase dike 15 feet thick was so thoroughly decomposed at a depth of 10 feet that less than 1 percent remained as exfoliated boulders; thus, surface indications of its presence must have been very scanty. It is probable that many dikes or parts of dikes were not detected during mapping. In several places, small patches of diabase occur along a line, but without any trace in the gaps. It is certain that the diabase bodies pinch and swell, but incomplete exposures and downslope creep of residual boulders must necessarily invalidate many measurements of thickness.

The eastern diabase belt (pl. 1) comprises a string of five echelon sills in gneiss that extends from near the State line just west of the Warren-Vance County line in a S. 12° W. direction entirely across and beyond the mapped area, a distance of more than 8 miles. Gaps, or apparent gaps, between the ends of sills within this belt range from 0.1 to 0.5 mile in length. Individual sills were traced for distances ranging from about 0.1 to more than 3 miles. Their thicknesses may in places be as little as 3 feet; they range up to about 125 feet, and for long distances are over 50 feet thick. In most places the sills are parallel to the foliation of the enclosing gneiss, but a quarter of a mile south of Bullocksville the diabase cuts at an angle of about 30° across the strike of the gneiss for half a mile and then resumes a concordant position. Several minor bends in the sills probably reflect similar structure in the gneiss, but this is not definitely known. Only diabase is known in this belt.

The central diabase belt, which is 4 to 5 miles farther west, extends 9 miles completely across the mapped area in a south-southwestward direction, passing a quarter of a mile east of Townsville and half a mile west of Williamsboro. It includes at least 10 large or fairly large dikes in albite granodiorite, as well as several smaller ones. The more northerly dikes trend about N. 70° E., but toward the southern end of the belt, the dikes bend to N. 25° E. Several of the more northerly dikes may actually be continuous with one another, but they could not be traced across the gaps shown. The three southernmost ones, near Williamsboro, end abruptly and the next in line begin at points so nearly perpendicular to their strikes as to suggest the possibility that they are offset by west- or northwest-trending faults. No other structural indication of displacement here was obtained and it is thought more likely that the dikes lens out. A discontinuous line of patches of float that begins at the southern limit of mapping at a point 1.7 miles S. 58° E. of Williamsboro and extends nearly a mile north-northwestward may constitute a fork of this belt. It has nearly the same trend as part of the main diabase belt 2 miles to the west. Individual dikes were traced for distances ranging from a few hundred feet to almost 2 miles. Thicknesses vary from 25 feet or less to 80 or 100 feet. Both diabase and hypersthene tonalite occur in this belt, the latter forming a single separate dike near Townsville.

The main diabase belt trends north along and near Little Island Creek more than 10½ miles and extends an unknown distance beyond the limits of mapping. It is about 3 miles west of the central belt at its northern end, but the two converge southward and almost meet at the south edge of the map. This belt includes a huge composite or differentiated branching dike that is continuous across the mapped area, three smaller dikes and sills, and several minor patches. The belt lies mostly in the central mass of albite granodiorite within 1 mile of its western contact, but its northern third is west of this contact in the phyllites. The principal body is a complexly branching dike in albite granodiorite along its southern 7 miles, where it consists mainly of eastern and western prongs that join or cross along some 3,000 feet, making a very oblique X. Both northern prongs of this X penetrate the tungsten mine and the contact between albite granodiorite and phyllite; the more westerly one seems to pinch out just after crossing the contact, but the eastern prong swings around to the north and becomes a sill in phyllites for at least 3 miles. For much of its length this body is 100 to 300 feet thick, and where the prongs of the X join, the thickness is about 500 feet. This dike-sill is composed of both diabase and tonalite mingled in a manner imperfectly understood (discussed later). The smaller dikes and sills of the main belt are mostly diabase alone, but one contains both rock types. Their thicknesses are mostly between 20 and 80 feet.

The western belt is 1½ to 2 miles west of the main belt and trends north for about 3 miles along the upper reaches of Island Creek, passing about 2¼ miles east of Bullock. Diabase forms six small sills or dikes in albite granodiorite, greenstone, and metafelsite; they may possibly be parts of one body. Though generally conformable to the local foliation, they appear in several places to be crosscutting, but no actual contacts were exposed. The group as a whole is discordant. Thicknesses seem to range from about 20 to 60 feet.

The strike pattern of the diabase dikes and sills (pl. 1) shows a marked preference for three directions—that is, north, N. 15° to 25° E., and N. 15° to 20° W. This is especially apparent for the largest dike of the main belt, where several branches trend a little east or west of north, though the general trend of the composite body is north. Even the sills of the eastern belt, though apparently largely controlled by regional foliation to the north-northeast, show local variations to north-northwest—for example, near Bullocksville. The central belt south of Townsville bends rather sharply more to the west and converges southwestward toward the main belt of dikes. Several individual dikes show rather abrupt similar strike changes. In the western belt the two more northerly sill-dikes bend or fork sharply in the indicated directions. Dips wherever determinable were essentially vertical.

The diabase dike directions show little relation to the joint trends (described later). In the eastern belt no joints were observed that strike north-northwest in the direction of the crosscutting parts of these dikes. In the central belt a moderate number of joints trend north-northeast, parallel to the principal dikes. In the main and western belts very few joints parallel the dikes. The diabase is greatly fractured, but no outcrops exposed the contacts in such a way that it could be determined whether joints passed continuously through diabase and wallrocks. Consequently, the relative age of the joints and the fractures occupied by diabase is uncertain, but the lack of correspondence in their orientations may indicate that the joints were formed after the dikes were emplaced. The fracturing that provided open cracks for the diabase intrusive bodies must have been Late Triassic and probably was distinct from movements causing other structural features in the district.

Fresh diabase is black or very dark greenish gray, but weathered diabase is reddish brown. The texture is usually medium grained and massive, but some is very fine grained. Lath-shaped dark plagioclase, greenish-black pyroxene, and magnetite can ordinarily be identified by hand lens. In places the dikes are so magnetic that the compass needle may be reversed. Little microscopic work was done on the diabase as its characteristics in the Atlantic Piedmont region are rather uniform and well known (Hotz, 1953, p. 678–702; Lester and Allen, 1950, p. 1219–1223; Reinemund, 1955, p. 54–60; Roberts, 1928, p. 43–62; Shannon, 1924, p. 1–86). Labradorite and augite are the chief components; lesser amounts of olivine, hypersthene, hornblende, magnetite-ilmenite, apatite, biotite, and microcline-quartz intergrowth are commonly reported.

Hypersthene tonalite is very closely associated with diabase in the central and main belts. Tonalite is restricted to those parts of the diabase belts that lie in albite granodiorite; it is not present, however, in all such areas. In the central belt, tonalite seems to be confined to a single occurrence where it forms a separate dike near Townsville. In general, however, it seems to be a component with diabase of dikes in the main belt and to be restricted to its southern two-thirds. The form and relations of these tonalite parts of diabase dikes could not be determined. Not a single outcrop showed both kinds of rock in place, but at many localities the float boulders of the two were intimately mixed. Tonalite float predominates in many small linear areas, suggesting conformable tabular units or closely spaced parallel dikes, but as a whole the distribution of the two rocks seems unsystematic. Field evidence fails to disclose whether tonalite constitutes differentiated portions of a single magmatic injection, or separate injections, earlier or later, of contrasting magmas into the same belts.

The tonalite is a medium-dark coarse-grained rock that superficially resembles the albite granodiorite of the district. Characteristically, however, the rock contains brown and dark-gray plagioclase, lacks biotite, and may have less quartz. The big tough exfoliated boulders strongly resemble those of diabase, and some tonalite may have been overlooked during the earlier phases of the mapping. The texture, on the whole, is coarser than that of diabase, but the largest grains are not more than 0.3 inch long. Thin sections of two specimens indicate that albite or oligoclase make up nearly half the rock, quartz about a quarter, hypersthene and a little microcline most of the rest. Accessory and secondary minerals include magnetite-ilmenite, titanite, apatite, zircon, pyrite, sericite, chlorite, leucoxene, and limonite. The plagioclase is fairly euhedral, in part zoned, and is considerably sericitized and iron stained. A section of an especially brown specimen showed abundant granophyre surrounding most of the rectangular oligoclase crystals. The feldspar that is intergrown with quartz in these borders is usually continuous with the crystal that the granophyre surrounds, suggesting that an earlier period during which oligoclase formed without quartz merged into a period of simultaneous crystallization of the two minerals. In its sodic plagioclase and granophyre the tonalite resembles certain silicic and alkalic rocks associated with diabase in Virginia and Pennsylvania (Hotz, 1953, p. 683–684, 701; Shannon, 1924, p. 4, 14–22; Tomlinson, 1945, p. 528–530) that are interpreted as differentiation products of diabase. Though no descriptions of rocks just like the tonalite were found, a similar origin for it is suggested by analogy.

The age of the diabase and associated rocks is presumed by analogy to be Late Triassic, though direct evidence of this is not available in the district. Diabase is intrusive into albite granodiorite and the quartz-huebnerite veins, which are regarded as younger than all the metamorphic rocks and the gabbro. The relation to aplite is not known, but since the latter seems to be related to granodiorite, aplite is probably older than diabase. Triassic sedimentary rocks in nearby areas are intruded by diabase, as for example in Granville, Durham, Orange, Chatham, Lee, and Moore Counties (Harrington, 1951, p. 150; Prouty, 1931, p. 480–481; Reinemund, 1955, p. 54). Because of the widespread distribution in Eastern United States of relatively uniform diabase that in many places cuts Upper Triassic sedimentary rocks, all these diabase bodies are regarded as of Late Triassic age.

AGE OF THE METAMORPHIC AND INTRUSIVE ROCKS

The relative age of the metamorphic rocks remains uncertain. The various phyllites are so intimately interbedded that they must be considered a single sequence. Greenstone is interlayered with phyllite at many places (see fig. 2), and, at least, much of it is likely to be essentially contemporaneous with the phyllites. The conglomeratic phase of the phyllites was not observed to contain fragments of greenstone or of metafelsites; so it is thought that the metavolcanic rocks are likely to be younger than the phyllites. Consistent with this conjecture is the occurrence of the metavolcanic rocks near the axis of the Spewmarrow syncline (described in the section on "Folds"), which lies between the Hamme and Virgilina districts, whereas the phyllites lie at a greater distance. Structural interpretation also, then, indicates that metavolcanic rocks probably lie higher in the stratigraphic section than the metasedimentary group.

The geologic age of these rocks also remains in doubt. No fossils have been found in them, and no radiometric analyses have been made. By analogy with conditions in the Arvonia and Quantico synclinal areas in Virginia, where Ordovician fossils were known (Watson and Powell, 1911, p. 35, 44), Laney (1917, p. 56) tentatively dated the metamorphic rocks of the Virgilina district (except the gneisses) as Ordovician. The Arvonia rocks, however, are regarded by Stose and Stose (1948, p. 404–405) as Silurian. Because of the similarities of the Virgilina and Hamme districts, it is presumed that the phyllites and metavolcanic rocks are likely to be of early to middle Paleozoic age. On the "Geologic Map of the United States" (Stose and Ljungstedt, 1932) they were classified as "Volcanic rocks (metabasalt or greenstone and aporhyolite)" of the Glenarm series (Algonkian?). On "The Geologic Map of North America" (Stose, 1946), however, they were referred to as "Paleozoic volcanic slate" of Silurian and Devonian ages.

The gneisses in the eastern part of the Hamme district were correlated by Jonas (1932, p. 231) with the Wissahickon formation of Precambrian age, of southern Pennsylvania, and on the "Geologic Map of the United States" (Stose and Ljungstedt, 1932) they were labeled "Wissahickon schist with igneous injection," a part of the Glenarm series. On the 1946 map, however, the gneiss belt was designated as "Later pre-Cambrian, post-Glenarm intrusive," thus drastically altering the interpretation of origin though retaining about the same age. The gradational relations between these gneisses and phyllites, already described, suggest that the two may be metamorphic variants of the same rock sequence. Whether the Precambrian or a Paleozoic age is correct is not settled.

Granites of this region have conventionally been considered late Paleozoic in age because of their undeformed character . On the "Geologic Map of the United States" (Stose and Ljungstedt, 1932) they were designated as "Carboniferous(?) granite, Pennsylvanian," though on the 1946 map (Stose, 1946) they were moved back a little, as "Carboniferous-Devonian granitic intrusive, Devonian and Mississippian." Data from the present investigation tend to indicate that the albite granodiorite, and probably some gneiss also, was derived from phyllites, but the date of this event is speculative. In view of the Ordovician and Devonian ages recently determined for granitic rocks farther west in North Carolina (Overstreet and Griffitts, 1955, p. 566), it appears reasonable that most of the rocks of the Hamme district are early Paleozoic or late Precambrian in age, and that the metamorphic and igneous events which affected them occurred during the latter half of the Paleozoic era.

Hornblende gabbro seems likely to be a little older than the albite granodiorite, but aplite and pegmatite are slightly younger.

Diabase and hypersthene tonalite are almost certain to be of Late Triassic age.

HYDROTHERMAL ROCKS

QUARTZ VEINS

A multitude of quartz veins occur throughout the district. They crop out more conspicuously than any other rock. Trains of loose quartz blocks in the soil are readily traced even where outcrops fail.

The veins are a fraction of an inch to about 25 feet thick and cut all types of bedrock but diabase and hypersthene tonalite (and perhaps also excepting aplite and pegmatite). Though veins are common in all parts of the mapped area, conspicuously large ones are localized near the western contact of the central mass of albite granodiorite, where they are somewhat more numerous in the granodiorite than in the foliated wallrocks. A smaller concentration of veins occurs in gneiss in the northeastern part of the mapped area, in western Warren County near the State line. Veins are smaller and less numerous along the west side of the mapped area. Only the larger and better exposed veins are shown on plate 1.

Most veins consist of quartz only, or perhaps contain a little scaly greenish sericite. Inclusions of phyllitic rocks are fairly common. The veins consist of either fine-grained or coarse-grained quartz. The fine-grained veins are sugary and fairly equigranular and have quartz particles about 0.25 to 2.0 mm long. Though the individual small grains are glassy, the luster of the rock is dull. The coarse grained veins consist wholly or largely of quartz masses and subhedral crystals that attain a length of 10 cm but are commonly 2 to 3 cm long. Many veins have coarse vugs lined with euhedral crystals, or they display comb structure. The quartz is opaque milky white or translucent vitreous and gray. Though each variety of quartz commonly appears to constitute the whole of an individual vein, both varieties also occur together. In these veins the coarser, vitreous quartz always forms veinlets and irregular masses cutting across the finer variety; thus, the coarse-grained quartz is distinctly later in origin.

Chalcedony forms thin coatings on quartz crystals in vugs of a few veins. The white or buff finely laminated crusts and botryoidal masses range from films to crusts that are as much as 4 mm thick. This material is likely to have formed during chemical weathering of formerly overlying rock. Silica released during decomposition of feldspar to clay may have been carried downward as colloids by ground water and precipitated in the small cavities.

A small percentage of the quartz veins contain minor amounts of other minerals—huebnerite, specular hematite, ilmenite, pyrite, and tourmaline. Veins containing these accessory minerals (excepting huebnerite-bearing veins) are uniformly distributed over the district and are found in most of the rock types. The quartz-huebnerite veins will be considered later in connection with the tungsten deposits. Specularite and ilmenite are commonly associated and often occur with tourmaline. Pyrite, and perhaps other sulfides, are comparatively uncommon in the district outside of the huebnerite-bearing veins. The sulfides in most places are completely weathered to limonite or are entirely leached away, leaving only iron-stained cubical molds in the quartz. There is relatively little gossan in the district. Black tourmaline forms irregular masses and sheaves of curved crystals that are commonly as much as an inch long; the largest mass noted was 8 by 4.5 by 1.5 inches. Tourmaline occurs in both fine- and coarse-grained quartz, but specularite, ilmenite, and pyrite are nearly confined to coarse-grained quartz veins. Very few of the coarse-grained veins that have vugs and comb structure, however, contain any mineral but quartz.

The form of the veins is lenticular to tabular. A few maintain uniform thickness for a large proportion of their strike length, but most vary rather abruptly in thickness in short distances. Some branch abruptly, and others consist of a cluster of only partly connected pods.

Trends appear to be mostly north to northeast, or near east-west, and less commonly to the northwest. No statistical analysis of the attitudes of the quartz veins was carried out. Dips are in almost all places steep to vertical.

These quartz veins are presumed to be related in origin to the processes that formed the central mass of albite granodiorite, though they fill fractures in granodiorite as well as in the wallrocks. Their age is greater than the Upper Triassic diabase, in which none are found, and which, on the contrary, crosscuts the quartz-huebnerite veins.

SILICEOUS ZONES

Five zones of unusual siliceous rocks were discovered in the district. Though differing from one another somewhat in character and setting, they all appear to be silicified bodies that consist largely of introduced silica formed mainly in brecciated areas.

In the northeastern part of the mapped area, in western Warren County just south of the state boundary, are two parallel, narrow siliceous belts, which trend north-northeast and are about 1,900 feet apart across strike. (See pl. 1.) The more easterly belt was traced about 2,500 feet, and the more westerly about 10,000 feet. In general, the siliceous bodies are parallel to the foliation of the enclosing biotite gneiss and dip steeply westward, but details of the only exposed contact show interfingering of quartz rock and gneiss. Thicknesses through much of their lengths seem to range from about 4 to 12 feet.

The rock is gray to buff and mostly very fine grained to aphanitic and has a waxy to porcelainlike luster on weathered surfaces. A network of veinlets have comb structure, and small irregular vugs lined with tiny quartz crystals are very numerous throughout the rock. Microscopic examination shows that the rock consists mainly of irregular patches of very fine grained, angular quartz particles having tangential contacts that are cemented and stained with limonite. A few shreds of muscovite are scattered through the rock, but muscovite is abundant in essentially cryptocrystalline areas. Grain shape and sorting indicate a siltstone. Crisscrossing through this fine-grained material are straight and irregular veinlets of coarser quartz, some of which have comb structure and subhedral to euhedral crystals. This rock is interpreted as a quartzose siltstone that has been brecciated and cemented by introduced silica.

A similar siliceous zone—reportedly called Devils Backbone—occurs in the central mass of albite granodiorite, about 2 miles southwest of Townsville. It is crossed by the road between St. Beulah Church and Marrow Chapel at a point 0.35 mile west of North Carolina Route 39. The zone follows an elongate S-plan for 1.2 miles; its strike gradually changes as traced northward, from north to N. 45° E. and back to north. Where exposed in the roadcut, the quartz rock occurs as irregular masses, a few inches to 4 or 5 feet thick, in buff to pink aphanitic rock, and in a zone that is about 17 feet wide. In this zone, quartz rock forms not much more than half the width. The aphanitic rock is almost entirely decomposed but appears to have been brecciated. On either side of the zone, decayed albite granodiorite that is unusually low in biotite is exposed. Ordinary quartz veinlets are numerous in the granodiorite just west of the siliceous belt. The siliceous rock itself consists mainly of cherty-looking, very fine grained to aphanitic material that has been minutely brecciated into angular particles about 1 mm to 1 cm wide. Microscopic examination shows these patches to consist of cryptocrystalline quartz with scattered larger angular quartz grains, and scanty shreds or patches of sericite; two small round zircon grains were observed. This material also contains a myriad of opaque specks, possibly limonite and leucoxene, that are brown or white in reflected light. Between those cryptocrystalline blocks is a complex of irregular veinlets of coarser quartz, partly forming mosaics and partly exhibiting comb structure and crystal-lined vugs. The original character of the fine-grained material is uncertain, but it is believed to have been a siliceous volcanic or dike rock similar to many in the western part of the district, and the zone may be interpreted as an inclusion in albite granodiorite or as an ungranitized remnant in the original terrane that has been brecciated and cemented by introduced silica. A possibility, suggested by the unusual scarcity of biotite in the albite granodiorite on either side of the siliceous zone and by the presence of large quartz grains in the cryptocrystalline silica of the zone, is that the Devils Backbone is an alteration zone in the albite granodiorite. However, a great deal of alumina and the alkalies would have had to be eliminated from the granodiorite to produce this highly siliceous, nearly sericite-free rock.

A quartz-sillimanite mass occurs in the southeastern part of the area mapped in detail (see pl. 1 and fig. 2), 1.7 miles southwest of Bullocksville, and a quarter of a mile north-northwest of locality 9. This mass lies within the central area of albite granodiorite, about 500 feet from its eastern contact with phyllites. It crops out as crags on a sharp ridge, trends N. 10° W., and apparently dips steeply westward. No contacts are exposed. It can be traced only about 300 feet, and where well exposed it ranges in thickness from about 20 to 35 feet. Both ends appear to terminate abruptly. On its east side is siliceous sericite phyllite. The rock is white to buff, very fine grained, largely massive, but in part poorly foliated. It is composed mainly of a mosaic of quartz particles that range in width from 0.3 to 0.03 mm. Scattered through this are a few lenticular, strained blue quartz grains 1 to 2 mm long and a little sericite. Sillimanite needles are abundant in most of the rock. In thin section, well-alined needles and trains of needles of sillimanite commonly form 10 to 20 percent of the field of view; in some sections 50 percent of the field is sillimanite. A few irregular kyanite grains, small round zircons, abundant irregular small rutile blebs, and many aggregates of small lazulite grains are present. Sillimanite needles replace quartz and kyanite but not zircon; lazulite replaces kyanite and sillimanite.

This quartz-sillimanite rock is the only high-temperature mineral assemblage observed in the district. It is closely associated with comparatively low-temperature sericite phyllite. Its origin is difficult to account for, as it seems to be incompatible with its surroundings. It appears that the sillimanite must be either a persistent relict from widespread high-temperature conditions, which has survived retrogressive metamorphism of all adjacent rocks, or that it was formed by very local concentration of high temperature. The former explanation seems unlikely because of the absence of other high-temperature relicts in the district and the uniform distribution of considerably lower temperature mineral assemblages. Further, if the closely associated sericite phyllite were formed during retrogressive metamorphism, comparable effects might be expected in the sillimanite-bearing rock. The alternative condition of high temperature restricted to a very small area is tentatively suggested for the origin of this rock. Local high temperature that was generated in slab of sericite phyllite, possibly along a narrow channelway leading to a fumarole, produced the quartz-sillimanite rock.

A siliceous zone forms a north-trending monadnock ridge in the western part of the strip of reconnaissance mapping (pl. 2), 6 miles N. 64° W. of Bullock in Granville County and three-quarters of a mile south of the State line. This area was visited only briefly and probably merits detailed examination. The light-gray to buff very fine grained rock seems to consist mainly of quartz. A little sericite is scattered through the massive rock, which is heavily specked with hematite or limonite. This is evidently a silicified zone in the phyllites that underlie this part of the area.

SURFICIAL DEPOSITS

UPLAND SEDIMENT

Flat upland areas and the upper slopes of the valley sides are commonly blanketed by unconsolidated sediment. These deposits rest unconformably on all the various types of bedrock, on an erosion surface that appears to be quite irregular. The bottom of the sediment cover is distinct where gravel or sand composes the basal layers, but commonly clay-rich sediment merges gradually downward into decomposed bedrock. Thicknesses of sediment range from about 1 foot to at least 16 feet.

The sediment consists mainly of silt and clay, with widely variable amounts of sand, pebbles, and rock fragments. Most is brown with limonite stain, but a good deal is light gray; in one place on albite granodiorite, blue quartz sand was so abundant as to tint the deposit. White, partially decomposed feldspar grains or mica flakes are abundant in a few places. Pebbles and cobbles, which are as much as a foot long, consist mainly of vein quartz but also include gneiss, albite granodiorite, diorite, diabase, and phyllite. Only rock types that are common in the bedrock of the immediate vicinity occur as gravel in the sediment, indicating that it has been transported only short distances. Consistent with this condition is the poor rounding of the great majority of pebbles and cobbles; in general only their edges and corners are distinctly rounded, and they would be termed subangular to subrounded. Quite at variance with these characters, however, is the fact that about a tenth of the quartz pebbles are completely rounded. These are especially common in the upper parts of the deposits. In most upland fields they are numerous in the soil.

The sediment is very poorly sorted. Stratification is ordinarily lacking or vague. No crossbedding was observed. In places, gravel forms thin irregular layers that are horizontal or gently dipping. In general, however, pebbles and blocks are scattered through sandy clay matrix. Except for the irregular distribution of subrounded quartz blocks and the presence of well-rounded pebbles, the material would in many places be indistinguishable from residual mantle in which primary texture had been destroyed by settling.

Brown-to-black concretions ranging from about 3 mm to 25 mm in thickness are very common in the soil. They are irregularly round and consist of sand cemented with limonite and probably manganese oxide.

This sediment is unconsolidated in most places, but some is fairly well compacted. At a locality 3 miles east-northeast of Townsville, on the west side of Nutbush valley, the sediment has been cemented into sandstone. The rock is composed of subrounded to angular quartz sand grains, mixed with some clay and weathered feldspar, and cemented by limonite. It contains a few subrounded quartz pebbles that are as much as 2 inches in maximum dimension, and in places it appears to be an aggregate of limonite-sand concretions. It covers the top of a small knoll as a group of rounded knobby hummocks, which are 0.5 to 1.5 feet thick and as much as 4 feet wide.

The apparently inconsistent features of the upland sediment have not been satisfactorily reconciled in a hypothesis of origin. Its location on the highest flat uplands seems anomalous and recalls the similar position of the terrace deposits in the Coastal Plain that are attributed to Pleistocene marine invasion. The elevations here, however, extend above 400 feet. The virtually unsorted and unstratified character of the deposit and the poor rounding of most of the gravel suggest a colluvial origin, but its occurrence on flat uplands precludes transportation by creep from higher areas. Most observations of the sediment, it is true, have been made in gullies on the upper slopes of the valley sides. These levels are sufficiently below the summit flats, so that mantle here may have moved downward and laterally by gravity. Creep may well have redistributed the sediment but could not have laid it down. The well-rounded pebbles are clearly present on the highest flat uplands and within areas covered by sediment. Thus, these pebbles must either be contemporaneous with the poorly sorted finer sediment or be later. Their high degree of roundness may, of course, be inherited from a prior cycle of sedimentation. The blanket of sediments extends in places down gentle slopes almost to the floodplain alluvium; hence, it appears to conform to the major features of present-day topography, though this matter was not studied in detail. The problem of age and conditions of deposition of this sediment is regional and will require special investigation.

FLOOD-PLAIN ALLUVIUM

The Roanoke River and its larger tributaries developed flat flood plains whose widths range from a few feet to half a mile. These bottom lands are underlain by unconsolidated sediment that in places is as much as 20 feet thick but generally is much less. The approximate limits of these deposits are shown on plate 1, though most are now inundated by Kerr Reservoir.

This alluvium commonly includes a basal layer of gravel or poorly rounded rock fragments. The bulk of the deposit consists of brown sandy clay in which stratification is marked mainly by recurrent gravel lenses. Some layers are black with organic matter. These deposits were laid down as channel bars and overflow sediment and most likely are of Recent age.

STRUCTURE

FOLIATION AND CLEAVAGE

Most of the rocks of the district, other than albite granodiorite and the intrusive rocks, have more or less distinct foliation, ranging from slaty or phyllitic cleavage, through coarser schistosity, to gneissic banding. The metafelsites and metabasalts in the western part of the district are ordinarily quite massive, but even these in many places split into rude slabs because of parallel mineral arrangement. In almost all places the foliation (cleavage) is parallel to the layers of varying composition and is due to parallel alinement of micaceous minerals.

Foliation at an oblique angle to bedding was recognized with certainty only at locality 4 (pl. 1) on bluffs north of the Roanoke River. In sericite-quartz phyllite, which was derived from argillaceous siltstone, the mica flakes are alined at an angle of about 30° to the bedding. Bedding strikes N. 80° E. and dips 45° NW. Cleavage strikes N. 40° E. and dips 80° NW. Their line of intersection plunges 37° to N. 30° E. These relations presumably indicate that the beds are right side up, that is, not overturned, and that younger rocks lie to the northwest. Thus, the phyllites are older than greenstone.

At one locality near Island Creek Dam, in similar rock, cleavage lies at about 30° to dark streaks which may represent bedding but which are believed more likely to be stain-filled fractures.

No exposures were found where beds reversed direction along fold axes so that the relation of cleavage to folds might be determined.

Structural symbols in the northwestern part of the area mapped in detail (pl. 1), near the junction of North Carolina Route 39 and U.S. Highway 15, show easterly dips of bedding though nearby foliation dips westward. This is probably not structurally significant, because both bedding and foliation are indistinct and were not recognized in the same exposure, and because in poor exposures some dikes may have been mistaken for bedding.

Practically all the foliation, then, is bedding foliation and presumably resulted from mimetic recrystallization of the layered rocks during regional metamorphism. Interlayer shearing may have helped orient the flaky minerals parallel to bedding.

The trend of the foliation in the district is uniformly north-northeast, and the strike rarely varies from place to place more than 20°. Along the northwest side of the central mass of albite granodiorite, near the Roanoke valley, the strike varies, as traced northward, from nearly north to northeast and back to north. The dip in nearly all the outcrops is steeply northwest, generally at angles of 65° to 85°, but in a few places as little as 40°. The few scattered southeast dips that were observed are not located in one or more belts so as to indicate the southeast limbs of folds. The prevailing steep northwest dips of parallel foliation and bedding across the whole district, coupled with the lack of repetition of rock units on opposite sides of an axial line, indicate a homoclinal westward dip, in the area mapped in detail, of a very great thickness of rocks.

LINEATION

Two kinds of lineation were noted in the district, in addition to the single place already described, of intersecting cleavage and bedding. Some equigranular mica gneiss in the eastern part has linear streaks of mica on the foliation planes. These lines are usually almost horizontal, an attitude that is typical of this gneiss belt farther southwest near Raleigh.

Phyllite in the western strip of reconnaissance mapping, 2 miles northeast of the town of Grassy Creek, has been minutely crenulated and incipient shear cleavage has developed. The phyllitic cleavage at this locality strikes N. 75° E. and dips 80° S. Axial planes of the wrinkles dip southward at only 10°, so that their axial lines are horizontal or plunge about 5° to N. 75° E. This lineation parallels the local strike of the rock units as they bend around the Spewmarrow syncline.

FOLDS

The overall structure of the district appears to be a homocline dipping steeply westward. The outcrop pattern (pl. 1) in places suggests that the rocks may have been isoclinally folded. No key beds exist, however, that could be traced so as to delineate major fold axes. The zigzag looping back and forth of some contact lines is not to be understood as indicating reversals of rock units around the ends of plunging fold axes, but rather as resulting from interfingering of lenticular rock masses. The contacts between the foliated and bedded units (phyllites, metafelsites, greenstones, and others) were drawn so that they enclosed areas within which one type predominated; these areas include also minor amounts of types that are dominant elsewhere. These contacts could not be traced along strike and were not observed to double back. They simply outline areas in which outcrops and float of a certain rock type were most common.

A small fold axis may exist in the northern part of the mapped area near the junction of Butchers Creek and the Roanoke River (pl. 1, loc. 1). On the south side of the Roanoke valley, conglomeratic phyllite lies both east and west of an unusual thickness of amygdaloid. Since rock of this character was observed in no other part of the district, these two masses may represent a sequence that has been folded around the southwest end of the amygdaloid. If the inferred relative ages of the rocks are correct, this fold would be a syncline plunging northeastward. Extension of the mapping along the northwest side of the area on both sides of the Roanoke River might show that the three separate greenstone areas were in fact continuous, in which case, additional minor fold axes might be evident. It may be speculated whether an anticlinal axis may not lie near the mouth of Island Creek so that the greenstone mapped south of the State line may extend northeastward and bend around to join the greenstone north of the river. This hypothetical structure may help explain the abrupt change in trend of the contact between phyllite and albite granodiorite near locality 5 (pl. 1).

A large syncline of possibly regional significance occurs in the strip of reconnaissance mapping (pl. 1 and 2) between the Hamme and Virgilina districts. Metavolcanic rocks (felsitic and basaltic) vary in strike through 180° around the end of a large gabbro pluton and dip southward toward it. Adjacent map units seem not to be completely repeated in reverse order on opposite sides of the axis. Specifically, the greenstone unit is not known to exist west of the axis beyond the metafelsites, but the author spent too little time here to be sure of its absence. Further, it may well have thinned out in the interval. This fold is here termed Spewmarrow syncline after the creek of that name which drains part of the area in the syncline to the northwest of Bullock. Along this axial belt (in part beyond the limit of mapping to northeast and southwest) are four large gabbro bodies. The possible structural interrelations of the Spewmarrow and Virgilina synclines are discussed under "Regional relations."

FAULTS AND DRAG FOLDS

Local zones of small-scale dislocation occur at many places in the district. At some localities both faults and minor folds are involved, while elsewhere one or the other occurs alone. These are decided exceptions to the prevailing uniformity of strike and dip; they seem to represent disturbances later than the period of regional dynamic metamorphism.

Faults in a few localities offset foliation, dikes, and veins. Where the slip can be determined, it is only a few inches or feet, and all the faults seem to be minor. The fractures range from low to high angle, with various strikes, and the displacements include normal, reverse, and strike-slip movements. A well-exposed example of faulted dikes is illustrated in figure 3.

Minor folds not associated with faulting range from crenulations and chevron folds in phyllite that approach strain slip cleavage to little anticlines and synclines in jointed metabasalt that have flank lengths of 1 to 1.5 feet. These occur east and west of the central albite granodiorite. Axes of these minor folds commonly plunge steeply (20° to 60°) in a wide range of directions. Drag folds noted by Espenshade (1947, p. 6) in the schistose rocks along the belt of tungsten veins indicate relative movement of the east side southward.

Most of the disturbed localities involve both faulting and bending of the rocks, the dominant feature probably being faulting. The zones seem to extend parallel to the general strike in the area, but each has been observed only in a single exposure. Width across the strike of the disturbed rocks is rarely as much as 10 feet, but at a point 4 miles northwest of Williamsboro it is 100 feet. Two examples about 1½ miles north of the tungsten mine are illustrated in figures 7 and 8. The dips of the fault zones are steep and the

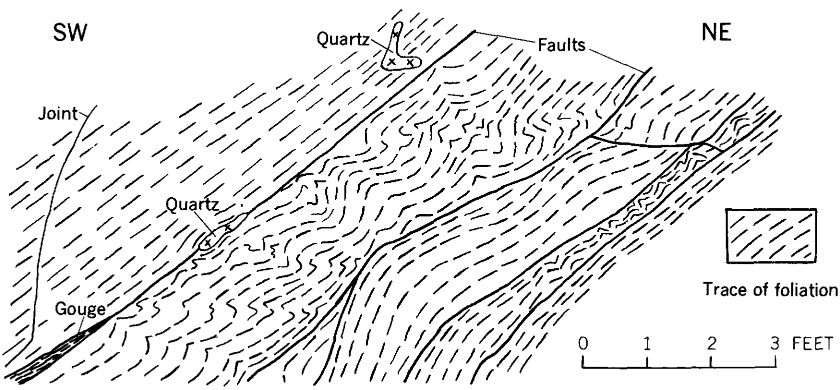

FIGURE 7.—Faults and drag folds in sericite- chlorite phyllite. Section extends N. 34° E. and slopes 40° SE., oblique to foliation, which is vertical and strikes north where not deformed. Displacement not certain, but southwest side probably moved down. Road cut on North Carolina Route 39, 0.25 mile south-southwest of the State line in Granville County, N.C.

direction of movement probably normal in general, but observations commonly are not conclusive.

No consistent picture of the overall directions and significance of the tectonic movements involved emerges from the scattered and fragmentary observations of these disturbed areas. They are known to have involved gneiss, phyllite, metabasalt, metafelsite, albite granodiorite, aplite, and quartz veins, so that some if not most of these movements occurred late in the region's history. Diabase and hypersthene tonalite are not known to have been affected, while most if not all older rocks seem to have been disturbed. These move-

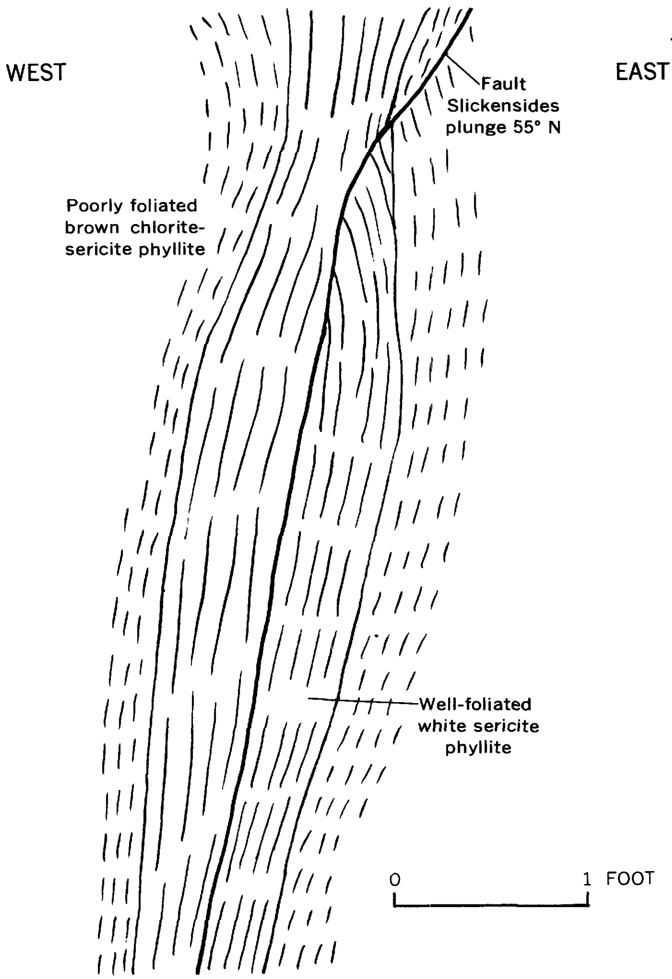

FIGURE 8.—Minor fault with drag in phyllite. Displacement is not certain, but west side probably moved down and away from viewer. Vertical east-west section in roadcut on North Carolina Route 39, 0.75 mile southwest of the State line, in Granville County, N.C.

ments probably antedated jointing (discussed below), which appears to have occurred after intrusion of diabase.

The belt of schistose rocks extending through the principal tungsten deposits that was mapped by Espenshade (1947, p. 6 and pl. 2) as a shear zone in the albite granodiorite is here interpreted as a phyllite inclusion.

White (1945, p. 100–101) inferred the existence of several cross faults from topographic evidence and an interpretation of aerial photographs. Espenshade (1947, p. 6), however, found no evidence of significant displacement along the west-northwest joints which exist there, and subsequent mapping fails also to confirm the presence of faults.

Diabase dikes half a mile north and west of Williamsboro (pl. 1) end abruptly with a pattern such as to suggest crossfaulting (as previously described), but the possibility is not believed to be strong.

JOINTS

Joints in the district are in general poorly developed. Locally, however, they are quite numerous and occur in distinct sets, most of which dip almost vertically. Detailed, statistical treatment of joints was not undertaken.

Rocks of all types exhibit jointing, but the fractures appear to be least common in albite granodiorite, more common in gneiss and phyllite, and most abundant in the massive metavolcanic rocks. Consequently, they are most noticeable in the western and eastern parts of the district and least noticeable in the middle. About half the joints observed tend to strike within 10° to 15° of east, the west-northwest directions being best represented. Directions near N. 45° E. are the next most numerous, with those near north and N. 45° W. slightly less well developed.

In albite granodiorite the four principal strike directions of the joints are about equally well represented, but at any one outcrop only one, or two at about right angles to each other, are usually present. In gneiss practically all the joints trend near east, more or less at right angles to the foliation and to the lineation of mica streaks. In phyllites three directions are more common. In the metafelsites and metabasalts three or four directions of joints are usual. Many of these have comparatively low dips, in contrast to the prevailing tendency toward the vertical. Outcrops of these hard, brittle rocks commonly have square, triangular, and rhombic forms as a result of close-spaced fractures. (See figs. 3, 4, and 9.) Jointing is likely to have occurred after intrusion of diabase (as was discussed under "Diabase and hypersthene tonalite") and hence may have attended later Mesozoic or Cenozoic regional uplifts.

REGIONAL RELATIONSHIPS

The Hamme Tungsten district is in the eastern part of the broad Carolina slate belt, an area of metasedimentary and metavolcanic rocks of low grade. The greater part of this belt in North Carolina (see King, 1955, geologic map; and North Carolina Div. Mineral Resources, 1958, Geologic map of North Carolina) lies west of the Triassic sequence, which overlies it unconformably and is down faulted into it. Slate belt rocks lie along most of the eastern side of the Triassic graben, and in the southern half of the State they extend eastward to and under the Coastal Plain sediments.

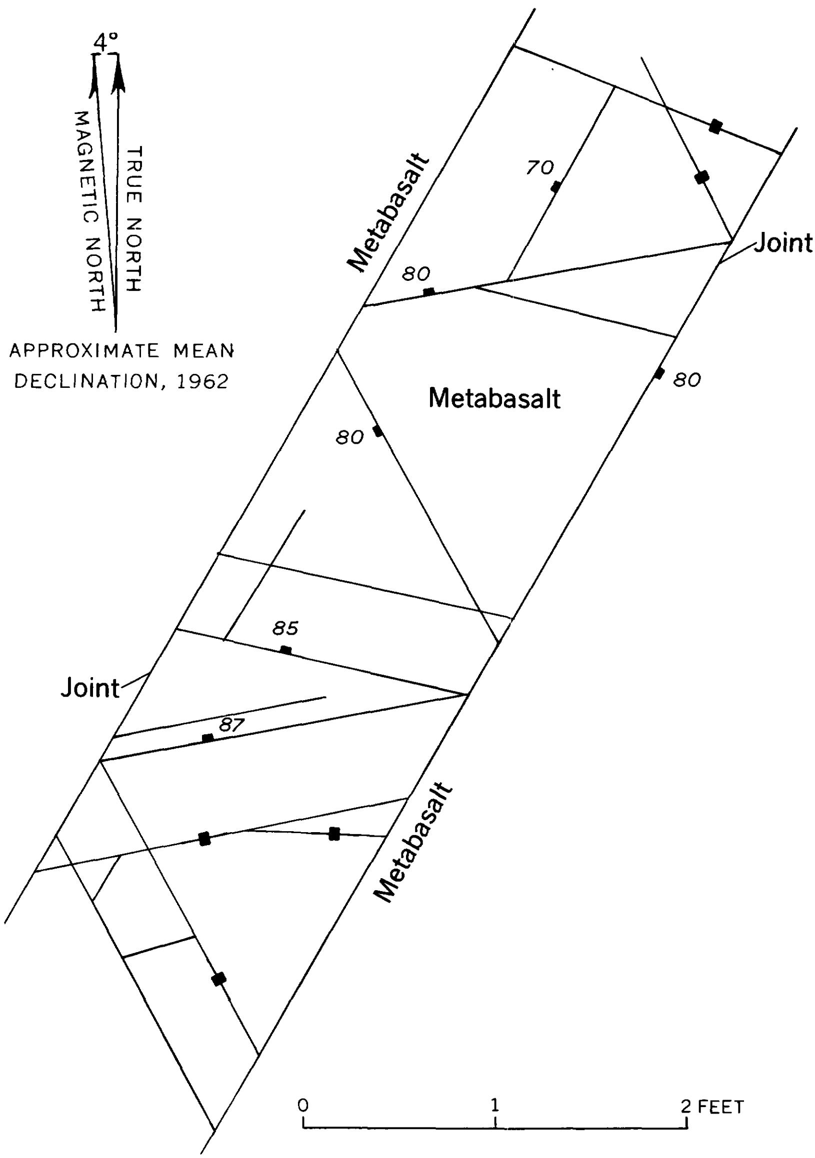

FIGURE 9.—Plan of joints in massive metabasalt in Island Creek, 2.3 miles S. 32° E. of Bullock, Granville County, N.C.

The Virgilina district lies along the western side of the Carolina slate belt in North Carolina and Virginia as shown by the "Geologic Map of North Carolina" (North Carolina Div. Mineral Resources, 1958) and the "Geologic Map of Virginia" (Stose, 1928). This district is interpreted by Laney (1917, p. 42–46) as a synclinorium made up of closely compressed folds overturned northwestward. He admitted, however, that other interpretations, which are not specified, are possible. Cleavage and bedding almost invariably dip steeply southeastward, though in places Laney noted northwest dips and bedding at an angle to cleavage. Repetition of map units on opposite sides of a central axis seemed to indicate a synclinorium because of the inferred relative ages of the volcano-sedimentary formations. These were believed to rest unconformably on gneisses and to be relatively younger from the margins of the mapped area to the center. Definite evidence for the unconformity and for the relative ages of the formations, however, was lacking. The bilateral symmetry of the Virgilina district, though evident near the North Carolina-Virginia boundary, is lacking in the northern part of the area. The synclinorial structure then, though plausible and even probable, is open to some doubt.

Because the Virgilina rocks almost invariably dip eastward toward the Spewmarrow syncline, whereas the dominant dip in the Hamme district is westward, it may be suggested that the rocks in these two districts constitute opposite limbs of a synclinorium of regional significance. Support for this idea is given by the positions of the two districts along the sides of the slate belt of low metamorphic grade, which is surrounded to the east, north, and west by gneisses of higher grade. The Spewmarrow synclinal axis is near the middle of this 35-mile-wide belt, though a little nearer the eastern side. The whole belt is commonly regarded as synclinal (see Am. Assoc. Petroleum Geologists, 1944, Tectonic Map of the United States; and Brown, 1954, pl. 1) and the name "Virgilina" is used to refer to it. If the suggested interpretation proves correct, it amounts to shifting the major synclinal axis about 12 miles eastward. Because the term "Virgilina synclinorium" has become so well established in a regional sense, it may preferably be applied to the major axis. An alternative interpretation is that the Virgilina and Spewmarrow synclines are of approximately the same magnitude, separated by an unmapped anticlinal axis. The eastern portion of the Hamme district, which is underlain by albite granodiorite and gneiss, may be part of a relatively uplifted or anticlinal belt that extends far northeastward and southwestward. The structural relationship of the Hamme and Virgilina districts is tentatively illustrated in the cross section in plate 2.

In the northern half of the eastern Piedmont in North Carolina, the part occupied by the Virgilina and Hamme districts, the slate belt rocks are interrupted by several north-northeastward-trending granite bodies and neighboring belts of gneisses and schists. Most small-scale geologic maps covering the region (Stose and Ljungstedt, 1932; Pardee and Park, 1948, pl. 1; North Carolina Dept. Cons. and Devel., 1937; Stose, 1928) were based on cursory reconnaissance only and hence are in some respects greatly in error. Their chief mistake was in exaggerating the amount of granite; instead of the five large persistent intrusive bodies represented, a much larger number of small, irregular lenses are scattered through the region, as shown on the new "Geologic Map of North Carolina" (North Carolina Div. Mineral Resources, 1958). The most prominent granitic belt in North Carolina extends through Warren County—east of the mapped area—and southwestward through Franklin and Wake Counties, and into Johnston County. The largest individual body in this belt extends across Wake and Franklin Counties but ends shortly after passing into the adjacent counties. In most places this belt of granite bodies is bordered on both sides by gneisses and schists; the gneisses on the west side of the belt extend westward into the Hamme district and are partly shown in plate 2. These gneisses extend northward across Virginia and have been correlated with the Wissahickon formation (Stose and Ljungstedt, 1932) of southeastern Pennsylvania. The slate belt type of rocks (mainly phyllites) are more abundant in this eastern Piedmont area of North Carolina than the more metamorphosed gneisses and the granite bodies, and in most places they constitute the most easterly basement rocks where the Coastal Plain sediments overlap the crystalline rocks.

Relations of the Hamme district to the adjacent Piedmont areas in Virginia beyond the area of mapping (pl. 2) are imperfectly known. General statements have been made by Brown (1954, p. 97–98), Nelson (1956, p. 1755–1756), and Pegau and Brent (1955, p. 1695), but detailed maps and descriptions are not available. The Virginia State geologic map (Stose, 1928) will need drastic revision in this area. Nelson (1956, p. 1755) believed the eastern Piedmont to be a great synclinorium lying southeast of the Blue Ridge–Catoctin anticlinorium and extending nearly to the Fall Line. It is composed of 4 synclinal and 3 anticlinal belts. The Hamme district lies about midway between "the Virgilina-Quantico syncline of Cambro-Ordovician age" and "the Gasburg syncline containing volcanics of Precambrian age," and hence, it is presumed, would be regarded as anticlinal in structure. Pegau and Brent (1955, p. 1695) reported in the southeastern Piedmont of Virginia four strips of north-northeastward-trending phyllite in a prevailing granitized schist-gneiss complex. None of these strips include the phyllite mapped by the author in the Hamme district and traced about 8 miles into Virginia.

MINERAL RESOURCES

Discovery in 1942 of tungsten in the eastern Piedmont of North Carolina has been followed by development of the deposits into a domestic source of first rank. Traces of many metals had been recognized in the old metamorphic and igneous rocks of the Carolina Piedmont for at least 150 years, but except for the 19th-century gold output, metal production had been more tantalizing than profitable. The small but actively growing mining industry of the region has exploited a wide variety of nonmetallic industrial minerals. Serious economic interest seems now to be justified in the metallic potentialities of the Carolina Piedmont.

TUNGSTEN DEPOSITS

Tungsten in the Hamme district occurs mainly as huebnerite (manganese tungstate) in quartz veins; a very little scheelite is associated closely with huebnerite. Fluorite is quite common in the veins, with small amounts of pyrite, galena, tetrahedrite, sphalerite, chalcopyrite, and rarely other minerals. The lenticular veins are localized in a narrow, north-northeast-trending belt about 7½ miles long and ½ mile wide; the great majority, and the richer veins, are concentrated in a 2-mile stretch near the center. The veins occur in phyllitic rock and in albite granodiorite near the western contact of the central mass of granodiorite. Details of the deposits may be obtained from publications by Espenshade (1943, 1947), Sweet (1954), and White (1945). The present investigation did not involve study of the deposits themselves.

Mining was begun by Joseph and Richard Hamme after their discovery of the deposits in May 1942. Their properties were acquired in August 1943 by Haile Mines, Inc., and operations were expanded. The Tungsten Mining Corp. was formed in June 1945 by Haile Mines, Inc., and General Electric Co. Steadily increased production of huebnerite concentrates allowed expansion in 1951–52 from 300 to 800 tons per day capacity. A chemical plant for converting low-grade concentrates to high-grade synthetic scheelite was added in 1955. Mining from two shafts and development work have progressed to the 1,500-foot level, and in 1957 extended along strike over a mile. Full accounts of mine and mill operations are available in articles by Hamme (1954), Sweet (1954), Waldron (1953), and Waldron and Walters (1953).

Production up to August 1954 is reported by Sweet (1954, p. 81) to total 577,000 short ton units of tungsten trioxide valued at $27½ million. The production of huebnerite concentrates by years for the period 1943–54 is given in table 3, data for which were supplied by and are published with the permission of the Tungsten Mining Corp.

The high-grade huebnerite concentrate contains from 70 to 73 percent tungsten trioxide (WO_3), according to Sweet (1954, p. 133).

Southern Aggregates Corp. mined some of the more northerly veins for a few months in 1943 and did some diamond drilling later. Northing is known of the production.

TABLE 3.—*Tungsten production of Hamme Mine of Tungsten Mining Corp., Vance County, N.C., 1943–54.*

[In short ton units of 20 pounds of tungsten trioxide (WO_3)]

Period	*Amount*
1943 (7 months, to July 31)	260. 65
1944 (11 months, to June 30)	6, 603. 48
1945 (12 months, to June 30)	12, 556. 76
1946 (12 months, to June 30)	7, 065. 22
1947 (12 months, to June 30)	33, 143. 00
1948 (12 months, to June 30)	36, 770. 24
1949 (12 months, to June 30)	63, 361. 38
1950 (12 months, to June 30)	57, 647. 44
1951 (12 months, to June 30)	63, 076. 99
1952 (12 months, to June 30)	61, 894. 24
1953 (14 months, to August 31)	128, 051. 81
1954 (9 months, to May 31)	104, 336. 13
Total	574, 767. 34

SULFIDES

Sulfides, mainly pyrite, were noted at about 18 places in addition to the few sulfide-bearing quartz veins. These localities have been noted on the geologic map (pl. 1) in the hope they may guide prospecting for mineralized belts. Almost all are along the northwest and west sides of the mapped area. Most are in greenstone and metafelsite and, in view of the ubiquity of pyrite in volcanic rocks, it is likely that it is a primary rather than an introduced mineral in these localities. The greatest concentration was noted in the area east and southeast of Bullock in eastern Granville County, where a number of occurrences fall in two north-trending lines parallel to the regional structure.

Green stain presumed to indicate copper sulfides occurs at two points near the Roanoke River on the northwest margin of the mapped area (pl. 1) 0.2 mile southwest of locality 1 and 0.75 mile northeast of locality 3.

To the west, in the area of reconnaissance mapping, pyrite occurs in phyllite in abundance on the Yancey farm at Jonathan Creek, about 2 miles west of the town of Grassy Creek. Pyrite was also noted about 1 mile farther south-southwest. These two localities are directly on strike with the siliceous zone that crops out on the monadnock 2 miles northwest of the town of Grassy Creek. This belt might merit prospecting.

CRUSHED STONE

Rock suitable for crushed stone occurs in the district but is not produced at present. Development of quarries in the district would be hampered by competition from nearby sources and by the lack of good sites near a railroad.

Albite granodiorite, gneiss, and diabase crop out at many places in the central and eastern parts of the district, but at most places are too deeply weathered to quarry. Topographically favorable locations are uncommon, but a small operation in albite granodiorite at the southeast side of Townsville might be possible. The western part of the mapped area is underlain by rocks of unsuitable physical character, except for small supplies of the less altered metabasalt or possibly of hornblende gabbro. Waste rock from the tungsten mine is used on a small scale to surface local secondary roads.

A large quarry where crushed stone is produced has been opened at Greystone, about 3 miles southeast of the mapped area. It is in the belt of biotite gneisses that extends along the east side of the district. The rock is quite varied, ranging mainly from fine-grained gray biotite gneiss to coarse-grained pink gneiss with little biotite. Some layers of biotite schist and of hornblende gneiss are interbedded, and sills or stringers of pink pegmatite are numerous. This operation is long established, the plant modern, and the conditions seem to favor continued large output of crushed stone.

Crushed stone used in construction for Kerr Dam was obtained from a newly developed quarry in Virginia, about 3 miles north of the dam and some 4 miles east of the northern limit of mapping. The rock is a moderately fine grained gneissic granite, very uniform throughout the quarry.

Reports by Watson and Laney (1906, p. 44–54) and by Councill (1954, p. 21–22) give further details of the stone industry and geology of the gneiss belt in North Carolina.

REFERENCES CITED

American Association of Petroleum Geologists, 1944, Tectonic map of the United States.

Argyle, B. E., 1946, Exploration of the Mecklenburg County, Virginia, tungsten area: U.S. Bur. Mines Rept. Inv. 3857, 5 p.

Bascom, Florence, 1896, The ancient volcanic rocks of South Mountain, Pennsylvania: U.S. Geol. Survey Bull. 136, 124 p.

Brown, W. R., 1954, Structural framework and mineral resources of the Virginia Piedmont: Virginia Geol. Survey Reprint series, No. 16, p. 88–111.

Councill, R. J., 1954, Commercial granites of North Carolina: North Carolina Dept. Cons. and Devel. Bull. 67, 59 p.

Darton, N. H., and Keith, Arthur, 1901, Description of the Washington quadrangles, D. C., Md., and Va.: U.S. Geol. Survey Geol. Atlas, Folio 70.

Espenshade, G. H., 1943, Tungsten deposits in Vance County, North Carolina, and Mecklenburg County, Virginia: U.S. Geol. Survey Strategic Minerals Inv. preliminary maps.

——— 1947, Tungsten deposits of Vance County, North Carolina, and Mecklenburg County, Virginia: U.S. Geol. Survey Bull. 948–A, 17 p.

——— 1950, Occurrences of tungsten minerals in the southeastern states; *in* Symposium on mineral resources of the southeastern United States, 1949, Proceedings: Knoxville, Tenn., Univ. of Tennessee Press, p. 56–61.

Glenn, L. C., Burwell, E. B., Espenshade, G. H., Kline, M. H., and McKeagney, R. B., 1948, Report on investigation of the Hamme Tungsten district in its relationship to the Buggs Island Reservoir, Roanoke River, Virginia-North Carolina: Mimeographed report by Advisory Board to District Engineer, 37 p., 17 pls., 1 fig. inc. index, geol. maps, April 1948.

Hamme, J. V., 1954, Steadily growing southeastern tungsten production: Mining Engineering, v. 6, no. 10, p. 978–982.

Harker, Alfred, 1932, Metamorphism: London, Methuen and Co., p. 40.

Harrington, J. W., 1951, Structural analysis of the west border of the Durham Triassic basin: Geol. Soc. America Bull., v. 62, p. 149–158.

Hotz, P. E., 1953, Petrology of granophyre in diabase near Dillsburg, Pennsylvania: Geol. Soc. America Bull., v. 64 ,p. 675–704.

Jonas, A. I., 1932, Structure of the metamorphic belt of the southern Appalachians: Am. Jour. Sci., 5th ser., v. 24, p. 228–243.

Keith, Arthur, 1903, Description of the Cranberry quadrangle, N.C. and Tenn.: U.S. Geol. Survey, Geol. Atlas, Folio 90.

King, P. B., 1955, A geologic section across the southern Appalachians, *in* Russell, R. J., ed., Guides to southeastern geology: Geol. Soc. America, p. 332–373.

Laney, F. B., 1917, Geology and ore deposits of the Virgilina district of Virginia and North Carolina: North Carolina Geol. and Econ. Survey Bull. 26, 176 p.; or Virginia Geol. Survey Bull. 14, 176 p.

Lester, J. G., and Allen, A. T., 1950, Diabase of the Georgia Piedmont: Geol. Soc. America Bull., v. 61, p. 1217–1224.

McIntosh, F. K., 1948, Investigation of the Hamme Tungsten district, Vance County, North Carolina, and Mecklenburg County, Virginia: U.S. Bur. Mines Rept. Inv. 4380, 6 p.

Mertie, J. B., Jr., 1953, Monazite deposits of the southeastern Atlantic states: U.S. Geol. Survey Inf. Circ. 237, 31 p.

——— 1956, Paragneissic formations of northern Virginia [abs.]: Geol. Soc. America Bull., v. 67, p. 1754–1755.

Misch, Peter, 1949, Metasomatic granitization of batholithic dimensions: Am. Jour. Sci., v. 247, p. 372–406.

Nelson, W. A., 1956, Structure and geology of the Virginia Piedmont [abs.]: Geol. Soc. America Bull., v. 67, p. 1755–1756.

North Carolina Dept. Cons. and Devel., 1937, Geologic map of North Carolina.

North Carolina Div. Mineral Resources, 1958, Geologic map of North Carolina.

Overstreet, W. C., and Griffitts, W. R., 1955, Inner piedmont belt, *in* Russell, R. J., ed., Guides to southeastern geology: Geol. Soc. America, p. 566.

Pardee, J. T., and Park, C. F., 1948, Gold deposits of the southern Piedmont: U.S. Geol. Survey Prof. Paper 213, 156 p.

Parker, J. M. 3d, 1953, Geology of the Hamme Tungsten district, Vance County, North Carolina [abs.]: Geol. Soc. America Bull., v. 64, p. 1534.

Pegau, A. A., and Brent, W. B., 1955, Granites and phyllites of southeastern Piedmont of Virginia and their relation to the tectonic map of this area [abs.]: Geol. Soc. America Bull. 66, p. 1695.

Pratt, J. H., 1901, The mining industry of North Carolina during 1900: North Carolina Geol. Survey Econ. Paper 4.

Prouty, W. F., 1931, The Triassic deposits of the Durham basin and their relation to the other Triassic areas of eastern United States: Am. Jour. Sci., v. 21, p. 473–490.

Ramberg, Hans, 1952, The origin of metamorphic and metasomatic rocks: Chicago, Univ. of Chicago Press, 317 p.

Reinemund, J. A., 1955, Geology of the Deep River coal field, North Carolina: U.S. Geol. Survey Prof. Paper 246, 150 p.

Roberts, J. K., 1928, Geology of the Virginia Triassic: Virginia Geol. Survey Bull. 29, p. 43–62.

Shannon, E. V., 1924, The mineralogy and petrology of intrusive diabase at Goose Creek, Loudoun County, Virginia: U.S. Natl. Mus. Proc., v. 66, art. 2, p. 1–86.

Stose, G. W., 1928, Geologic map of Virginia: Virginia Geol. Survey.

——— 1946, Geologic map of North America: Geol. Soc. America.

——— [assisted by Ljungstedt, O. A.], 1932, Geologic map of the United States: U.S. Geol. Survey. .

Stose, G. W., and Stose, A. J., 1948, Stratigraphy of the Arvonia slate, Virginia: Am. Jour. Sci., v. 246, p. 393–412.

Sweet, J. R., 1954, Tungsten mining in North Carolina: Min. Cong. Jour., v. 40, p. 81–86 and 132–133.

Tomlinson, W. H., 1945, Notes on the derivatives of the diabases in Pennsylvania: Econ. Geol., v. 40, no. 8, p. 526–536.

Turner, F. J., and Verhoogen, Jean, 1951, Igneous and metamorphic petrology: New York, McGraw-Hill Book Co., 602 p.

Waldron, H. L., 1953, Hamme mine doubles productive capacity: Mining World, v. 15, no. 10, p. 46–50 and 67.

Waldron, H. L., and Walters, L. J., 1953, Tungsten Mining Corporation's expanded mill: Mining World, v. 15, no. 12, p. 42–46.

Watson, T. L., and Laney, F. B., 1906, Building and ornamental stones of North Carolina: North Carolina Geol. Survey Bull. no. 2, 283 p.

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

White, W. A., 1943, Tungsten deposit near Townsville, North Carolina: North Carolina Dept. Cons. and Devel., Mineral Inv. 1, 9 p.

——— 1945, Tungsten deposit near Townsville, North Carolina: Am. Mineralogist, v. 30, p. 97–110.

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