The Crystalline Rocks of South Carolina

GEOLOGICAL SURVEY BULLETIN 1183

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By WILLIAM C. OVERSTREET *and* HENRY BELL III

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Relation of rock units in the geologic belts of the Piedmont and Blue Ridge provinces of South Carolina

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1965

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C., 20402

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ABSTRACT

A provisional geologic map of the western half of South Carolina showing the crystalline rocks and the edge of the overlapping sediments of the Atlantic Coastal Plain was prepared in 1960 at a scale of 1 : 250,000 and published by the U.S. Geological Survey in 1965 as Miscellaneous Geologic Investigations Map I–413. The present report is a description of the crystalline rocks depicted on that map. The positions of the lithologic units shown on the geologic map have been interpreted from published soil maps of the counties, from published and unpublished geologic maps representing but a small part of the State, and from the distribution of heavy minerals in streams draining areas of residual soil and saprolite in the western Piedmont. The units thus shown on the map are lithologic rather than time-stratigraphic units.

The crystalline rocks of South Carolina are grouped for discussion into six northeast-trending lithologic belts which are interpreted to be zones of different grades of regional metamorphism. Present grades of metamorphism are the resultant of four main metamorphic episodes in the Appalachian region that culminated about 1,100, 550, 450, and 260 million years ago.

The names of three of the lithologic belts are well established in the geologic literature, and the names of two others were introduced by P. B. King in 1955. The easternmost belt is called the Carolina slate belt. It is composed typically of greenschist facies metasedimentary rocks and of metavolcanic rocks, but its metamorphic rank is more varied than that of the other belts. It is succeeded northwestward by the Charlotte belt, which is composed of feldspathic gneiss and migmatite of the albite-epidote amphibolite facies. A narrow belt, the Kings Mountain belt, of metasedimentary and metavolcanic rocks—mainly greenschist facies and albite-epidote amphibolite facies—separates the west side of the Charlotte belt from the Inner Piedmont belt. The Inner Piedmont belt is composed of sedimentary and volcanic rocks that have been metamorphosed to the staurolite-kyanite and sillimanite-almandine subfacies of the amphibolite facies. Bordering the Inner Piedmont belt on its northwestern side is a narrow zone of blastomylonite and phyllonite called the Brevard belt. Most of these cataclastic rocks are of the greenschist facies, and they form a zone 2–4 miles wide along a great strike-slip fault on which the horizontal displacement appears to have been too great to be measured in South Carolina alone. In the Blue Ridge belt, west of the Brevard belt, are ancient metasedimentary rocks of the amphibolite facies which have no known exposed counterpart in the Piedmont.

The metamorphic rocks exposed east of the Brevard belt appear to consist of three sequences of geosynclinal sediments, the lowermost of which rests on ancient Precambrian rocks that are not exposed in the Piedmont. The three sequences of sediments accumulated in successive subsiding basins during late

Precambrian and Paleozoic time. Although the sedimentary sequences are separated by erosional unconformities that can be traced from one belt to another, the sedimentary rocks in the three sequences broadly resemble one another and are thus very difficult to distinguish. Originally, they consisted of the following: Graywacke; shale; felsic tuffaceous siltstone, tuff, and flows; mafic tuffaceous siltstone, tuff, and flows; together with sparsely interbedded conglomerate, sandstone, limestone, and manganese-rich shale. The manganese-rich shale may be restricted to the upper sedimentary sequence, but the other rocks are in all three sequences.

Two unconformities are exposed in the three sequences in the Piedmont, and an unexposed unconformity probably separates these three sequences from the ancient basement.

In the more than 150 years that have elapsed since geologic observations were first made in South Carolina, no fossils have been found in the crystalline rocks. However, studies of the lead-alpha ages of 53 samples of zircon and monazite from the Carolinas were undertaken as part of this investigation. Results of these studies together with published reports on the ages of other minerals from the same area show that the lower of the two observed unconformities is between rocks that are probably of Cambrian and Ordovician ages and that the upper of the two is between rocks that are probably of Devonian and Mississippian ages. The unexposed unconformity at the base of the three sequences of metamorphosed sedimentary rocks in the Piedmont is between rocks that most likely are of early Precambrian and late Precambrian or Cambrian age. Thus, the three sequences of metamorphosed sedimentary rocks in the Piedmont of South Carolina are late Precambrian and Paleozoic in age. Metamorphosed sedimentary rocks in the Blue Ridge belt are early Precambrian in age. The blastomylonite of the Brevard belt may have been formed between Permian time and Late Triassic(?) time, for it appears to be younger than intrusive rocks of Permian age in the Piedmont and older than diabase dikes of Late Triassic(?) age.

A wide variety of intrustive rocks—of which the most distinctive are granite, muscovite pegmatite, gabbro, syenite, and diabase—are found in the belts. The granite ranges in age from Cambrian to Permian, most of it being Ordovician or Permian. Distinct relations were found between the shape of granite masses and the belts in which they crystallized. Layered, folded, and concordant granite masses are characteristic of the Inner Piedmont belt. Crosscutting granite fills fractures in the Kings Mountain and Charlotte belts. Plutons shaped like inverted tear drops occupy folds along the margins of the Charlotte and Carolina slate belts. Muscovite pegmatite dikes from which commercial muscovite has been mined are restricted to the belts of metamorphosed sedimentary rocks of the upper amphibolite facies—that is, the Inner Piedmont and Blue Ridge belts. They do not occur in the Charlotte belt, where the largest granite plutons are found, but they do occur where the metamorphosed sedimentary rocks are mainly of the albite-epidote amphibolite facies. A late series of igneous rocks forms small stocks and dikes of gabbro, pyroxenite, peridotite, and syenite. Zircon-rich syenite pegmatite dikes with thick wall zones containing as much as 50 percent vermiculite are related to this group of intrusives. Diabase dikes of Late Triassic(?) age cut the other crystalline rocks. Apparently, igneous activity in the Piedmont did not cease with the intrusion of this diabase for beds of bentonite of Eocene and Miocene age crop out in the Coastal Plain of South Carolina, and they contain sharply terminated euhedral crystals of zircon of probable pyroclastic origin. As yet no intrusives in the Piedmont have been related to this probable volcanic activity.

The successive periods of folding and metamorphism tended to expel water and mobile ions from the resulting highly compressed plutonic rocks. Escape of these substances partly accounts for the metasomatism of the less plutonic rocks and may also account for some of the mineral deposits in South Carolina.

INTRODUCTION

The complex geology of the crystalline rocks in South Carolina is poorly known. Very few geologic maps of the Piedmont or Blue Ridge provinces in South Carolina have been published, and these are mostly of small areas or are regional maps merely including South Carolina. Geologic maps resulting from the work of Michael Tuomey, Oscar M. Lieber, and others between 1848 and 1859 were consolidated by Hammond in 1883 into a geologic map of the State of South Carolina. The map was printed in color at a scale of 1 inch equals 10 miles, but it apparently remained largely unknown because it was not indexed by Boardman (1950), nor described by Johnson (1959). Later compilations of the geology of South Carolina appear to have been based mainly on the work of Lieber between 1856 and 1859 and of Earle Sloan between 1904 and 1910.

The need for a geologic map of the crystalline rocks of South Carolina, which was neither satisfied by the map compiled by King (1955) nor by the earlier maps of Lieber (1858a, 1859, 1860), Hammond (1883), and Sloan (1908), became apparent in the course of our work in North and South Carolina. Our attention was directed to the soil maps of the U.S. Department of Agriculture, which are the result of the most complete and detailed fieldwork done by earth scientists in South Carolina. These maps provide an excellent starting point for compiling a geologic map because residual soils predominate in that part of South Carolina underlain by crystalline rocks. A large geologic map, begun in 1958 and completed in June 1960, was compiled largely by interpretation of these soil maps. This map, published at a 1:250,000 scale as U.S. Geological Survey Miscellaneous Geologic Investigation map I–413, provides a base for our interpretation of the structure, stratigraphy, and metamorphism in this area. These interpretations are summarized on plate 1. The discussion that follows, however, including geographic references is based on the large geologic map (Overstreet and Bell, 1965).

Methods of compilation.—Soil maps and reports dating from 1903 to 1943 are available for all but three of the South Carolina counties that contain crystalline rocks. Each of these reports includes a description of the soils as well as brief comments on the rocks from which the residual soils were derived. Most of the soils in the area underlain by crystalline rocks are residual (Tuomey, 1844, p. 27)—that is, they are formed in place from the weathering and decomposition of the underlying rock formations. For this reason the residual soils reflect, in varying degrees, the underlying rocks.

To make the geologic map (Overstreet and Bell, 1965), we reviewed the report and soil map of each county and made an overlay to show the major rock types that we believe gave rise to the various soil series. In each county the rock type that underlies a particular soil was determined from a direct statement in the text, from some characteristic of the soil described in the text and known by us to be related to some particular rock, or from descriptions of similar soils derived from known rocks in adjacent counties. Although residual soils having similar appearance may form from rocks of widely differing character; in general, the soil series are closely related to major rock types. Table 1 shows some of the common soil series and the major rock types from which the residual soils were formed. Soils developed on rocks of the Coastal Plain and on alluvium are included.

Each county soil map was interpreted in terms of rock type, combined with other county maps into a map of the entire area, and then interpreted geologically. Thus the units shown on the geologic map (Overstreet and Bell, 1965) are lithologic units and not necessarily stratigraphic units. The soil maps of parts of Cherokee, Spartanburg, Greenville, Anderson, Pickens, and Oconee Counties show residual soils so similar that we were unable to interpret the complex geology known to exist; hence, for these counties the geology is based largely on other sources of information, such as the report on the Pisgah quadrangle by Keith (1907), the report on the Gaffney and Kings Mountain quadrangles by Keith and Sterrett (1931), an unpublished geologic map of Pickens County by C. Q. Brown, and hitherto unpublished work of the U.S. Geological Survey.

Fieldwork.—Four weeks were used for fieldwork in connection with the large geologic map. During 1 week in September 1959, 2 weeks in May 1960, and 1 week in December 1960, many of the larger rock units were visited to check soil interpretation and add structural data to the map. During the short time available for fieldwork, little else could be done. No attempt was made to revise the location of geologic contacts in detail. Information gained from our fieldwork beginning in 1948 in connection with several other projects in the Piedmont of the Carolinas contributed largely to the geologic interpretations included in the map (Overstreet and Bell, 1965) and in this text.

Acknowledgments.—The geologic map made from the soil maps includes much additional information obtained from the literature; from members of the U.S. Geological Survey, particularly A. A. Stromquist and J. C. Reed, Jr.; and from our friends in South Carolina. We wish to acknowledge particularly the help of Henry S.

TABLE 1.—*Major rock types and related soil series*

Major rock types		Soil series and type	Soil and subsoil color and characteristics	Remarks
Igneous and metamorphic rocks.	Argillite, tuffaceous argillite, and graywacke; all are brown, greenish brown, and gray and fine grained; include both silicic and mafic rocks.	Georgeville series; includes fine sandy loam, silt loam, silty clay loam, and clay loam.	Gray to red soils; red silty clay subsoils.	Residual soils derived in place from the weathering and decomposition of underlying rock formations.
		Alamance series; includes very fine sandy loam, silt loam, and clay loam.	Gray soils; yellow silty clay subsoils.	
		Goldston silt loam. Orange silt loam. Conowingo silt loam.		
	Gneiss, schistose gneiss, gneissic granite, granite, syenite, schist, quartz-mica schist, and quartzite; all are fine-to coarse-grained predominately silicic rocks.	Cecil series; includes gravelly sandy loam, sand, coarse sandy loam, sandy loam, fine sandy loam, loam, silt loam, sandy clay loam, clay loam, and clay. Madison gravelly sandy loam.	Many variations in color, texture, and structure; largely brownish yellow, reddish brown, or gray; red subsoil. Forms rolling to hilly topography on which erosion is active.	
		Hayesville sandy loam and loam. Porter series; includes stony loam, fine sandy loam, loam, clay loam and clay. Pilot loam.	Similar to Cecil soils but largely confined to hilly or mountainous areas.	
		Ashe loam.		
	Mica schist.	Louisa series; includes sandy clay loam and clay loam.		
	Banded gneiss and interlayered dark hornblende gneiss and light-colored granitic gneiss.	Lloyd clay loam.		
	Granite, gneissic granite, and coarse porphyritic granite; all are light colored and medium to coarse grained.	Appling series; includes coarse sandy loam, sandy loam, and fine sandy loam.	Gray to yellowish-gray soils and yellowish-red to mottled light-red and yellow subsoil.	
		Durham series; includes coarse sandy loam, sandy loam, fine sandy loam, and loam.	Gray to pale-yellow soils and yellow or yellowish-gray subsoils.	

TABLE 1.—*Major rock types and related soil series*—Continued

Major rock types		Soil series and type	Soil and subsoil color and characteristics	Remarks
Igneous and metamorphic rocks.	Amphibolite, diorite, gabbro, pyroxenite, and norite; all are dark colored, fine to coarse grained, massive or foliated; included are areas having abundant dikes of diabase, basalt, andesite, and lamprophyre, predominately mafic rocks.	Iredell series; includes stony loam, coarse sandy loam, sandy loam fine sandy loam, loam and clay loam.	Grayish-brown or brown soils and yellowish-brown to brown heavy plastic clay subsoils.	
		Mecklenburg series; includes loam and clay loam.	Brown or reddish-brown soil and reddish-brown or yellowish-brown heavy stiff clay subsoil.	
		Davidson clay loam.	Dark-red or reddish-brown soil and dark-red or maroon heavy stiff clay subsoil.	
Sedimentary rocks.	Thin Coastal Plain sedimentary rock; high-level sand and gravel overlying weathered and decomposed igneous and metamorphic rocks.	Bradley sandy loam.	Gray to brownish-gray soil and heavy red residual subsoil.	
		Chesterfield coarse sandy loam.	Gray soil and yellow, mottled white and gray, heavy residual subsoil.	
	Alluvium along streams in, or originating in, areas of igneous and metamorphic rocks; subject to overflow.	Congaree series; includes fine sand, fine sandy loam, silt loam, and silty clay loam.	Brown to reddish-brown soil and light-brown, mottled yellow and brown subsoil; commonly has small mica flakes.	
		Meadow; unclassified as to series; includes loose sand, loam, and silt loam.	Similar to Congaree soils but extremely varied in color, texture, and structure; includes much material not developed into a definite soil.	
		Wehadkee series; includes silt loam, and silty clay loam.	Gray to brownish-gray soil and mottled gray, yellow, and brown heavy subsoil.	
	Alluvium occurring as terraces along streams in, or originating in, areas of igneous and metamorphic rocks.	Altavista series; includes fine sandy loam, silt loam, and loam.	Gray soil and yellow to mottled yellow and gray subsoil.	
		Wickham series; includes fine sandy loam and loam.	Brown or dark-brown soil and reddish-brown or yellowish-red subsoil.	
	Alluvium along streams on the Coastal Plain.	Thompson loam. Johnston loam.	Poorly to very poorly drained soils and friable-sandy-loam to sandy-clay-loam subsoils.	Soils derived from transported material.

Alluvium occurring as terraces along streams on the Coastal Plain.	Amite series. Cahaba series. Kalmia series. Myatt series. Leaf series. Okenee series.	Finely textured soils, heavy subsoils, and characteristic level topography.
Sedimentary formations of the Coastal Plain.	Marlboro series. Norfolk series. Orangeburg series. Ruston series. Dunbar series. Coxville series. Grady series. Portsmouth series. Greenville series. Hoffman series.	Soils varied in color, texture, and structure but characteristically sandy.

Johnson, Jr., State Geologist of South Carolina; Prof. L. L. Smith and Prof. J. F. McCauley of the University of South Carolina; and Prof. C. Q. Brown of Clemson College. Their help and our other sources of information are acknowledged by county on the geologic map.

GENERAL GEOLOGIC RELATIONS

GEOLOGIC BELTS AND PHYSIOGRAPHIC PROVINCES

The geologic map (Overstreet and Bell, 1965) shows sedimentary rocks of Mesozoic and younger age and metamorphic and igneous rocks of Paleozoic and Precambrian(?) age generally distributed in northeast-trending belts. The beltlike distribution of the rocks, and of the soils formed on them, has long been recognized in South Carolina. As early as 1802, Drayton (p. 10–11) observed that the State was divided into three belts of distinctive physiographic character; and in 1819, Dickson amplified this observation. Sloan (1908, pl. 1) divided the crystalline rocks of South Carolina into 13 lithologic zones to facilitate his discussion of the geologic history and economic geology of the State. Jonas (1932, p. 230–231) proposed regional names for three great belts of metamorphic rocks in the southeastern Piedmont, and she related the belts to inferred major overthrust fault blocks. In 1955 King (p. 337–338) proposed a group of names for belts in the southern Appalachians, showed their relations to physiographic provinces, and discussed their geology. Seven of King's geologic belts are present in South Carolina. Six belts are underlain by crystalline rocks; and, from southeast to northwest, these belts are the Carolina slate belt, Charlotte belt, Kings Mountain belt, Inner Piedmont belt, Brevard belt, and Blue Ridge belt. These are shown on plate 2.

In South Carolina the Brevard and Blue Ridge belts and the westernmost part of the Inner Piedmont belt are in the Blue Ridge physiographic province. The rest of the area of crystalline rocks is in the Piedmont physiographic province, which gives way southeastward to the Atlantic Coastal Plain geologic belt and physiographic province. The part of South Carolina in the Blue Ridge province is only a very small part of the total area of the State in which metamorphic and igneous rocks are exposed. The main area of outcrop of these rocks is in the Piedmont.

GEOLOGIC BELTS AND STRATIGRAPHIC SEQUENCES

The beltlike distribution of the metamorphic and igneous rocks of Paleozoic and Precambrian(?) age in South Carolina provides a convenient way to discuss these rocks. Some rock units in the Piedmont have many features in common; so, we postulate that they may also be stratigraphic units. We also think that these stratigraphic units extend across the geologic belts in the Piedmont. The stratigraphic succession inferred from the large geologic map (Overstreet and Bell, 1965) indicates that the geologic belt eastward from the Brevard belt are probably zones of different grades of regional metamorphism imposed on a great thickness of volcanic and sedimentary rocks much modified by folding and by the intrusion of igneous rocks. Separating the belts in the Piedmont from the Blue Ridge belt is a fault zone marked by the Brevard belt. The gneisses and schists in the Blue Ridge belt appear to be older than the rocks in the Piedmont.

BLUE RIDGE PROVINCE

The Blue Ridge belt is here interpreted to be composed of ancient metasedimentary rocks of the amphibolite facies into which igneous rocks of Paleozoic age were emplaced. No stratigraphic sequence has been worked out for the rocks of the Blue Ridge belt in South Carolina.

The Brevard belt in the Blue Ridge province is here interpreted to be a strike-slip fault zone which separates the rocks of the Inner Piedmont belt from those of the Blue Ridge belt. Brevard rocks are typically phyllonite and blastomylonite derived from gneisses and schists in the adjacent belts. They are therefore not a stratigraphic sequence.

PIEDMONT PROVINCE

The metamorphic rocks of the Carolina slate, Charlotte, Kings Mountain, and Inner Piedmont belts in South Carolina, we infer, originated as three sequences of sedimentary rocks separated by two erosional unconformities (table 2; pl. 1). All three sequences were originally composed of shale, graywacke, felsic and mafic tuffaceous shale, tuff, and lava flows containing thin and sparsely interbedded conglomerate, sandstone, and limestone. Each sequence was deposited in a subsiding basin, and the successive basins of deposition were superimposed in the South Carolina Piedmont. To the east the margins of the basins are covered by the unmetamorphosed sedimentary rocks of the Atlantic Coastal Plain, and to the west the basins extended at least to the Brevard belt. Along strike to the northeast and southwest, these basins appear to have extended at least into Virginia and Alabama.

The sequences of metasedimentary rocks can best be observed in the Carolina slate belt and in the Kings Mountain belt, where they are least metamorphosed. Fortunately, the rocks of these two belts merge in South Carolina across the Charlotte belt (pl. 2), and a stratigraphic

TABLE 2.—*Inferred stratigraphy and related intrusive rocks in the Piedmont of South Carolina*

	Succession of sedimentary, pyroclastic, and extrusive rocks east of the Brevard belt					Succession of intrusive rocks east of the Brevard belt				
	Sandstone and shale of Late Triassic age					Diabase dikes				
Succession of sedimentary and intrusive rocks west of the Brevard belt (in Blue Ridge belt)	Sequence of sedimentary and pyroclastic rocks	Inner Piedmont belt	Kings Mountain belt	Charlotte belt	Carolina slate belt	Intrusive episode	Inner Piedmont belt	Kings Mountain belt	Charlotte belt	Carolina slate belt
					Unconformity					
							Syenite pegmatite		Minette and syenite pegmatite	Minette and syenite pegmatite
								Syenite	Syenite	Syenite
							Gabbro, pyroxenite, and norite	Gabbro and pyroxenite	Gabbro, pyroxenite, and norite	Gabbro, pyroxenite, and norite
Ultramafic dikes (in part)							Muscovite pegmatite			
	Upper					C	Cherryville Quartz Monzonite	Cherryville Quartz Monzonite	Granite, circular plutons at Chester, Winnsboro, and Liberty Hill	Granite, circular plutons at Winnsboro, Liberty Hill, and Cayce
							Yorkville Quartz Monzonite	Yorkville Quartz Monzonite	Yorkville Quartz Monzonite	
		Marble (in part)	Marble							
		Biotite schist (in part)	Sericite schist (in part)	Mica gneiss (in part)	Argillite (in part)					
		Quartzite (in part)	Quartzite							
			Sericite schist (in part)		Muscovite schist (in part)					
					Unconformity					
Muscovite-perthite pegmatite										

Whiteside Granite Metamorphosed ultramafic and mafic dikes (in part)		Biotite granite gneiss					Toluca Quartz Monzonite Metamorphosed gabbro and soapstone	Metamorphosed gabbro Oligoclase tonalite	Metamorphosed mafic dikes	Metamorphosed mafic dikes
	Middle	Biotite schist (in part) Marble (in part) Quartzite (in part) Henderson Gneiss Biotite gneiss and migmatite (in part) Hornblende gneiss (in part)	Sericite schist (in part) Hornblende schist	Mica gneiss (in part)	Argillite (in part) Muscovite schist (in part) Quartzite Quartz-microcline gneiss Amphibolite	B				
					Unconformity					
	Lower	Hornblende gneiss (in part) Biotite schist (in part) Biotite gneiss and migmatite (in part)	Granitoid gneiss	Granitoid gneiss	Granitoid gneiss	A	Biotite gneiss at Iva, Anderson County	Not recognized	Porphyritic granite in Abbeville County and gneissic granodiorite in York County	Not recognized
					Unconformity (unobserved in the Piedmont)					
Hornblende schist and gneiss Biotite schist and gneiss	Basement				Unobserved in the Piedmont					

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succession could be worked out for a large part of the crystalline rocks in the State. The sharp tectonic break at the Brevard belt is also a distinctive lithologic break; rocks resembling the sequences observed in the Piedmont have not been seen west of the Brevard belt.

Lower sequence.—The lower sequence of metamorphosed sedimentary rocks in the Piedmont of South Carolina is most readily recognized in the Charlotte belt in the area shown as granitoid gneiss on the geologic map (Overstreet and Bell, 1965). Although the granitoid gneiss consists of a variety of rocks and certainly includes infolded rocks of younger age, we interpret the unit to have been originally composed mainly of graywacke, arkose, shale, and pyroclastic rocks with thin local layers of limestone. Mafic volcanic rock was interbedded with these sediments, but the amount was considerably less than that subsequently deposited in the overlying sequences. The granitoid gneiss was later fissured and widely intruded by mafic dikes which cut the younger sequences in the Piedmont.

The central part of the Inner Piedmont belt we also interpret as being composed of the lower sequence of metamorphosed sedimentary rocks. It too has less mafic volcanic material than do younger sequences of sedimentary rocks.

The rocks on which the lower sequence of sediments was deposited have not been recognized in the South Carolina Piedmont. We think the basement under the Piedmont consists of Precambrian polymetamorphic gneisses and schists similar to the pre-Ocoee rocks of the Blue Ridge belt in the southeastern part of the Great Smoky Mountains (King, 1955, p. 359–360).

Middle sequence.—The middle sequence of metamorphosed felsic and mafic volcanic rocks, tuffaceous argillite, graywacke, sandstone, and minor amounts of carbonate rocks extends in broad folds from the Carolina slate belt across the Charlotte belt into the Kings Mountain belt (pl. 1). We think that it also exists as hornblende gneiss and biotite schist in tight folds along the eastern edge of the Inner Piedmont belt.

Rocks in the Kings Mountain and Gaffney quadrangles that we include in the middle sequence were thought by Keith and Sterrett (1931, maps) to be part of the Precambrian basement on which later sedimentary rocks were deposited; but southeast of the Gaffney area, particularly in Chester and Fairfield Counties, this middle sequence of rocks evidently overlies an older sequence of metasedimentary rocks that was not seen by Keith and Sterrett.

The middle sentence of sedimentary rocks in the slate belt is in part called amphibolite and muscovite schist on the geologic map (Overstreet and Bell, 1965). These rocks lie above the granitoid gneiss of the Charlotte belt. At many places the granitoid gneiss is intricately fractured and intruded by swarms of metamorphosed andesite and basalt dikes which we interpret to be feeders for the mafic volcanic rocks in the middle sequence. Despite subsequent deformation and metamorphism, the mafic dikes can still be recognized by their difference in composition compared to the wallrocks. Feeder dikes for the felsic volcanic rocks, however, have been only rarely observed.

We have not seen an unconformity between the middle and lower sequences at any outcrop; but we infer one from structural divergencies in Chester, Fairfield, Saluda, and Abbeville Counties—from the greater abundance of mafic flows in the middle sequence—and from the presence of dike swarms in the lower sequence but not in the middle sequence.

Upper sequence.—The upper sequence of metasedimentary rocks in the Piedmont was found in the Carolina slate belt by us, as well as by Keith and Sterrett (1931, maps) and Potter (Espenshade and Potter, 1960, p. 70); it was also recognized by us in the northern part of the Kings Mountain belt in South Carolina. In more highly metamorphosed parts of the Piedmont, these rocks have not yet been identified.

The upper sequence of metasedimentary rocks in the slate belt originally consisted of shales, pyroclastic rocks, local thin carbonate-rich beds, and rare manganese-rich beds. The sequence overlies felsic and mafic volcanic rocks that are widely intruded by mafic dikes, principally altered gabbro. Similar dikes do not intrude the upper sequence. We interpret the absence of these dikes from the upper sequence to mean that the upper sequence was deposited unconformably on the middle sequence and its gabbro dikes.

The upper sequence in the Kings Mountain belt consists of metamorphosed pyroclastic rocks and laminated argillites, marble, quartzite, and manganese-rich schist and is remarkably similar in lithology to the upper sequence of rocks in the slate belt. Furthermore, it uncomformably overlies hornblende gneiss, biotite schist, and biotite gneiss which are similar in composition and origin to the felsic and mafic volcanic rocks of the middle sequence in the slate belt and which are likewise intruded by dikes of metamorphosed gabbro. Because of the similarities in lithology between the upper sequence of sedimentary and the pyroclastic rocks in the Kings Mountain and Carolina slate belts and because both units overlie similar rocks intruded by dikes of metamorphosed gabbro but are not themselves intruded, we infer that they are correlative sedimentary sequences (pl. 1). They are the youngest group of metamorphosed sedimentary and pyroclastic rocks that we identified in South Carolina.

SUCCESSION OF INTRUSIVE ROCKS IN THE PIEDMONT

Field observations of the plutonic intrusive rocks exposed in South Carolina and the relation between them and the metasedimentary rocks disclose a long and complex succession of intrusive events. All the intrusive rocks and their metamorphic hosts are cut by diabase dikes of Late Triassic(?) age; therefore, the plutonic intrusive rocks are all probably older than Late Triassic. Our interpretation of the relations among the intrusive rocks is illustrated in table 2.

Lower sequence.—All the intrusive rocks observed in South Carolina east of the Brevard belt cut the lower sequence of metasedimentary rocks and presumably cut the unexposed underlying rocks. At one place, a locality 4.5 miles east of Iva, Abbeville County, gneiss of probable intrusive origin has structural relations which we interpret to indicate that the gneiss underlies but is not intrusive into the middle sequence of metasedimentary rocks. The rock is a coarse-grained biotitic gneiss in the biotite schist unit of the Inner Piedmont belt. The gneiss contains coarse euhedral crystals of zircon as much as 0.3 inch long. From their large size and sharp edges we infer that these zircon crystals formed in an intrusive rock. The trend of the gneiss at this locality is athwart the trend of the nearby Kings Mountain belt, and the unconformity that we infer at the bottom of the middle sequence of metasedimentary rocks lies between this gneiss and the rocks of the Kings Mountain belt. Similar gneiss has not been found in the Kings Mountain belt. We interpret these relations to mean that this gneiss intrudes the lower sequence of metasedimentary rocks but is older than the middle sequence.

Greatly fractured gneissic granodiorite in the Charlotte belt is intermittently exposed west of U.S. Highway 21 between the Catawba River and Rock Hill, York County, S. C. It locally contains inclusions of fine-grained biotite schist and has many blocks of faulted and offset mafic dikes. Its distribution is too poorly known to show on the large geologic map (Overstreet and Bell, 1965), but the rock closely resembles gneissic granodiorite exposed about 25 miles to the northeast in Cabarrus County, N.C. The rock in Cabarrus County is intrusive into schist and is intruded by a complex of metamorphosed mafic dikes, granite, and syenite. The structural relations there (Bell and Overstreet, 1959, p. 1–5) show that the gneissic granodiorite is the oldest intrusive rock in the Charlotte belt in that area. Its position in the regional framework is, however, not well known. Uncertainty arises as to whether the gneissic granodiorite is intrusive into the lower or middle sequence of metasedimentary rocks in South Carolina. Slate belt rocks whose relations are undetermined crop out nearby and may be infolded with the gneissic granodiorite. Rocks of the slate belt are considerably less metamorphosed than the gneissic granodiorite. The strongest evidence for the geologic position of the gneissic granodiorite is the presence of the mafic dike swarms in it. Their presence suggests that the gneissic granodiorite is part of the lower sequence on which were spread the vast mafic flows at the base of the middle sequence of sedimentary and pyroclastic rocks in South Carolina.

Middle sequence.—Most of the known intrusive rocks in South Carolina east of the Brevard belt intrude into or through the middle sequence of metasedimentary rocks. A few of these intrusive rocks are unconformably overlain by the metasedimentary rocks of the upper sequence. Felsic rocks intrusive into the middle sequence can be divided into rocks that were intruded before or after a group of gabbro dikes. Wherever these gabbro dikes are now seen, they are metamorphosed. In South Carolina the best known example of felsic bodies that were intruded before the gabbro dikes is the small masses of oligoclase tonalite in York County. These felsic bodies are fractured and intruded by metamorphosed gabbro. The oligoclase tonalite and the gabbro are unconformably overlain (Espenshade and Potter, 1960, p. 70; Keith and Sterrett, 1931, maps) by the sedimentary and pyroclastic rocks of the upper sequence.

Granitic rocks younger than the metamorphosed gabbro cut the gabbro and contain inclusions of it. Thick reaction rims of biotite are commonly formed around the inclusions. Some of these granitic rocks form migmatitic complexes that are older than the upper sequence of metasedimentary rocks and are cut by late usually massive granite bodies, by muscovite pegmatite dikes, and by late unmetamorphosed dikes of gabbro, syenite, and syenite pegmatite. The Toluca Quartz Monzonite in South Carolina and the granite intrusive into gneissic granodiorite in Cabarrus County, N.C., belong to the group of felsic intrusive rocks associated with the middle sequence but not with the upper sequence.

Upper sequence.—Discordant plutons of granitic rocks, associated muscovite pegmatite dikes, and discordant bodies of gabbro, norite, syenite, syenite pegmatite, and minette make up the last intrusive episode to affect the Piedmont of South Carolina prior to the intrusion of diabase dikes of Late Triassic(?) age. Discordant plutons of granite in the eastern Piedmont form distinctive circular to elliptical bodies (Overstreet and Bell, 1965) near Chester, Winnsboro, Liberty Hill, and Cayce. In the north-central part of the Piedmont, discordant plutons have a linear shape and are called Yorkville Quartz Monzonite and Cherryville Quartz Monzonite. They cut across the unconformity between the middle and upper sequences of metasedimentary rocks in Kershaw, York, and Cherokee Counties.

The muscovite pegmatite dikes in the Piedmont of South Carolina must have formed at the time these late granitic rocks were emplaced because they are very rarely intruded by any rocks.

Discordant bodies of unmetamorphosed gabbro, syenite, syenite pegmatite, and minette intrude the youngest granitic rocks but are not intruded by them. In the Kings Mountain belt in Union County, the unmetamorphosed gabbro and syenite intrude parts of the upper sequence, which in every respect resemble the Battleground Schist of Keith and Sterrett (1931, p. 4–5).

GEOLOGIC BELTS AND REGIONAL METAMORPHISM

The geologic belts east of the Brevard belt differ from each other mainly in what has happened to the original sedimentary rocks after they were deposited. The modifications brought about by folding, regional metamorphism, and igneous intrusion changed them into the rocks now exposed. We believe the geologic belts in South Carolina to be metamorphic zones superimposed on a regional stratigraphic sequence. The inferred position of the main facies of regional metamorphism is shown on plate 3. If plate 3 is compared with plate 2, the congruence between geologic belts and metamorphic facies can be seen.

The belts, because they are mainly metamorphic zones, cut across other regional features such as stratigraphic units, unconformities, and folds. A superb example of a stratigraphic unit crossed by metamorphic zones is the amphibolite unit of the Carolina slate belt; this unit extends across the Charlotte belt to the Kings Mountain belt. Another example is the layers of marble, quartzite, and manganese-rich schist in the Kings Mountain belt that extend into the Inner Piedmont belt. Unconformities in one belt are traceable into another belt. At least one and possibly two unconformities can be followed from the slate belt across the Charlotte belt into the Kings Mountain belt. Folds in one belt persist in trend into another belt. Large anticlines and synclines in the Charlotte belt, shown on plate 1, persist into the Carolina slate belt. Parallelism of small folds in these two belts is shown by the parallelism of small linear and planar features plotted on the geologic map (Overstreet and Bell, 1965).

The metamorphic rocks reflect processes that operated at different pressures and temperatures, and in that sense the geologic belts mark zones of different degrees of deformation.

The character of deformation varies among the belts according to the intensity of metamorphism. Deformation is progressively weaker and less plutonic eastward from the Inner Piedmont belt, where plastic flow of the rocks is dominant, through the Kings Mountain and Charlotte belts, where repeated fracture is the main pattern, to the

Carolina slate belt, where the fractured and folded rocks range from excellently cleaved to uncleaved.

The regional metamorphic belts change in metamorphic grade along their trend as well as across it. Decrease in metamorphic grade associated with folds in the Charlotte belt in McCormick County accounts for the appearance of the low-grade rocks of the slate belt. A rise in metamorphic grade takes place in the Kings Mountain belt in Laurens County, but unusual lithology at this place permits the belt to be traced through to the low-grade rocks near Georgia. We think that in Cherokee County the typical metamorphic facies of the Kings Mountain belt is locally erased by rise in metamorphic grade, and a zone of rocks indistinguishable from Inner Piedmont or Charlotte belt rocks is formed.

Local contact metamorphism marginal to granite plutons has made a variety of small changes in the different belts. In the Inner Piedmont belt there appears to be some reduction in the abundance of garnet in the gneisses around late granites. Intense tourmalinization is very common and is of many ages. Strong rise in metamorphic grade adjacent to the late granites is common in the Kings Mountain belt but uncommon in the Carolina slate belt. Indeed, contact-metamorphic effects in slate belt rocks around circular plutons are barely evident; where the same pluton cuts across Charlotte belt gneiss, it creates perceptible retrogressive metamorphism.

The metasedimentary rocks in the Inner Piedmont belt are separated from those in the Blue Ridge belt by a strike-slip fault that formed the Brevard belt of phyllonite and blastomylonite. It is the largest fault in South Carolina, and we can find no correlative units on opposite sides of it. Possibly displacement on the Brevard fault is so great that it cannot be measured in the State of South Carolina alone. A lengthy high-angle normal fault that trends east-northeast (plate 1) is associated with the sandstone and shale of Late Triassic age near Pageland, S.C., and cuts across phyllites of the slate belt southwest of Columbia; this fault appears to be an extension of the Triassic border fault in North Carolina. Vertical displacement on the fault may be at least 10,000 feet; but metamorphic effects resulting from its movement, apparently confined to cataclasis, are not great.

DESCRIPTION OF ROCK UNITS

The rock units of Paleozoic and Precambrian (?) age shown on the geologic map (Overstreet and Bell, 1965) are divided for convenience of description into assemblages observed in the six geologic belts. Descriptions of the sedimentary and igneous rocks of Mesozoic and younger age are discussed separately because they cannot be grouped with the belts of older rocks. Use of the belts as a way to classify the rocks was adapted to the status of geologic knowledge at the time the map was compiled. In the future it would seem desirable to classify the metamorphosed sedimentary and volcanic rocks on the basis of stratigraphic sequence and metamorphic facies and to relate the descriptions of igneous rocks to the intrusive episodes. A great deal of field data must be added to the present fund of information before this can be done with reasonable accuracy.

ROCKS OF PALEOZOIC AND PRECAMBRIAN(?) AGE

CAROLINA SLATE BELT

The term Carolina slate belt has long been used in the literature to define the easternmost belt of low-rank metamorphic rocks exposed in the Piedmont of the Carolinas. Olmsted called attention in 1824 to the low metamorphic rank, local excellent cleavage, and distinctive fissile property of the rocks when he named them "the great Slate Formation" (Olmsted, 1824, p. 23–24). He described the rocks as clay slates in which beds of porphyry, soapstone, serpentine, and greenstone were unusually common and true roofing slate was lacking. He thought the fissile rocks in the formation to be sedimentary in origin, as did Emmons (1856, p. 41–45) and Kerr (1875, p. 131–132). The volcanic nature of some of the rocks in the slate belt in South Carolina was mentioned by Lieber in 1860 (p. 44–45) and described by Williams in 1894 (p. 30). Shortly thereafter the volcanic origin of a substantial part of the rocks in the North Carolina segment of the belt was recognized by Nitze and Hanna (1896, p. 36), but Nitze and Hanna continued to call the belt the Carolina slate belt. Detailed work in North Carolina by Laney (1910, p. 25–41; 1917, p. 18–33), Pogue (1910, p. 26–28), and Stuckey (1928, p. 16–25) tended to emphasize the volcanic origin of the rocks and led to the use of the terms Volcanic slate belt (Broadhurst, 1950, p. 9) and Volcanic-slate series (Broadhurst and Councill, 1953, p. 5–7), although Buie and Robinson (1949, p. 4–5) adopted the term Slate belt in South Carolina and King (1955, p. 337–338) used the name Carolina slate belt for the rocks exposed in North and South Carolina. The role of sedimentary processes in forming the rocks of the belt was reemphasized by John M. Parker (in King, 1955, p. 344). Stuckey and Conrad (1958, p. 27) remarked that, because of the large volumes of nonvolcanic sediment in the Carolina slate belt in North Carolina, abandonment of the term "volcanic" in unit descriptions on the geologic map of North Carolina was considered but not adopted. More recently, Stromquist and Conley (1959, p. 3) suggested the name Carolina volcanic-sedimentary group for the rocks in the belt. In Georgia this belt of rocks is known as the Little River Series (Crickmay, 1952, p. 31–33).

Over a period of 140 years, this belt in the Carolinas has been successively called the great Slate Formation, the Carolina slate belt, the Slate belt, the Volcanic slate belt, the Volcanic-slate series, and the Carolina volcanic-sedimentary group. Emphasis has shifted in the recent nomenclature from the recognition of a belt to the description of a lithology; and, in the effort to refine the lithologic expressions, the grander concept of a belt of fissile rocks has been partly lost. Despite the absence of true slate and the presence of volcanic rocks, the name by which the belt has longest and most often been called in the literature is Carolina slate belt. We think no other name is equally well adapted for the belt in South Carolina.

The southeastern edge of the slate belt is covered by sedimentary rocks of the Atlantic Coastal Plain. At Dillon, S.C., just outside the mapped area and 26 miles southeast of Bennettsville, rhyolite breccia of the slate belt was reached in a well that penetrated 594 feet of Coastal Plain rocks (Siple, 1958, p. 67). The northwestern edge of the slate belt merges into the gneisses, schists, and granitoid rocks of the Charlotte belt. A series of folds in the northern part of McCormick County exposes low-rank metamorphic parts of the slate belt. These small infolded masses probably merge southwestward in Georgia with the main mass of the Carolina slate belt on the south and with the Kings Mountain belt on the north. A similar correlation of rocks in the slate belt with those in the Kings Mountain belt can probably be made along the border between Union and Chester Counties where amphibolites of the two belts appear to merge. Thus, part of the rocks in both the Carolina slate belt and the Kings Mountain belt may belong to the same sequence of sedimentary rocks, an idea long postulated (Emmons, 1856, p. 51; Kesler, 1936, p. 34; King, 1955, p. 343; Stromquist and Conley, 1959, p. 3) but never proved.

The rocks in the Carolina slate belt are shown on the large geologic map (Overstreet and Bell, 1965) amphibolite, quartz-microcline gneiss, quartzite, muscovite schist, and argillite. The probable relations between these map units and probable stratigraphic units in the slate belt are shown in table 3, and the approximate position of the two unconformities listed in table 3 are marked on plate 1.

The amphibolite is an extensive unit of the Carolina slate belt in South Carolina. It is sharply defined on the soil maps. We think that it may be a stratigraphic unit; and, as such, we have assigned it a major role in our stratigraphic and structural interpretation. The amphibolite is the stratigraphically lowest unit in the slate belt except locally, as between Flint Hill and Mitford in Fairfield County, where it is underlain by a thin group of felsic flows and sedimentary rocks. Overlying the amphibolite are felsic volcanic rocks which, like the amphibolite, are intruded by metamorphosed mafic dikes. The felsic volcanic rocks occur in both the muscovite schist unit and in the argillite unit, neither of which is a stratigraphic unit. The position of the top of the felsic volcanic rocks intruded by mafic dikes is not certainly known, but we thought it to be along the northern part of the broad band of argillite and muscovite schist in upper Saluda County and in Newberry County and along the southern side of the argillite unit in lower Saluda County and Lexington County. The amphibolite seems to unconformably overlie the metamorphic rocks in the Charlotte belt, which appear to be among the oldest rocks in the Piedmont. In Richland County the amphibolite disappears, and southwest of this point the felsic volcanic rocks and overlying argillite lie on older metamorphosed rocks in the Charlotte belt. We think that the amphibolite and the felsic volcanic rocks intruded by mafic dikes are the remnants of a depositional cycle which unconformably overlie older rocks and are unconformably overlain by younger rocks in the muscovite schist and argillite units.

TABLE 3.—*Probable relations between map units used by Overstreet and Bell (1965) and stratigraphic units in the Carolina slate belt of South Carolina*

<table>
<tr><th colspan="3">Map units</th><th>Inferred stratigraphic sequence</th><th>Sequence of sedimentary and pyroclastic rocks</th></tr>
<tr><td rowspan="3">Argillite</td><td rowspan="3">Muscovite schist (partly metamorphic equivalent of argillite unit)</td><td rowspan="3">Mica gneiss (Charlotte belt)</td><td>Argillite, tuffaceous argillite, and graywacke; include felsic and mafic agglomerates, breccias, tuffs, volcanic flows, and rhythmically banded sediments; local carbonate- or manganese-rich layers; not intruded by mafic dikes.</td><td>Upper</td></tr>
<tr><td>Unconformity</td><td></td></tr>
<tr><td>Similar to the above rocks, but containing more felsic volcanic rocks and intruded by mafic dikes.</td><td rowspan="5">Middle</td></tr>
<tr><td colspan="4">Stratigraphic contact</td></tr>
<tr><td colspan="3" rowspan="3">Amphibolite</td><td>Amphibolite, hornblende schist, hornblende gneiss, actinolite schist, and chlorite schist; some diorite, metagabbro, and biotite gneiss; intruded by numerous mafic dikes.</td></tr>
<tr><td>Local stratigraphic contact</td></tr>
<tr><td>In Fairfield County, some muscovite schist derived from felsic tuff and argillite; intruded by mafic dikes.</td></tr>
<tr><td colspan="5">Unconformity</td></tr>
<tr><td colspan="3">Granitoid gneiss (Charlotte belt)</td><td>Undifferentiated granitoid gneiss, gneissic granodiorite, gneissic granite, biotite-muscovite schist, and biotite-muscovite gneiss.</td><td>Lower</td></tr>
<tr><td colspan="5">Unconformity (not observed)</td></tr>
<tr><td colspan="5">Basement (not observed in South Carolina)</td></tr>
</table>

METAMORPHOSED SEDIMENTARY AND VOLCANIC ROCKS

AMPHIBOLITE

The unit called amphibolite forms distinctive long, arcuate, and irregular bodies in Chester and Fairfield Counties and small extensions of these bodies in York and Union Counties. The amphibolite, as mapped, consists of dark-gray, green, and black amphibolite, hornblende schist, hornblende gneiss, actinolite schist, chlorite schist, and biotite-hornblende schist which we interpret to be the metamorphic equivalents of basaltic and andesitic lavas and tuffs. Less mafic rocks in the unit are interpreted as intercalated graywacke and tuffaceous argillite. The metamorphic grade of these volcanic rocks is not everywhere the same, but throughout its extent the unit is distinctly mafic.

Metamorphosed mafic lavas and tuffs make up the bulk of the amphibolite unit and account for many of the broad areas of dark schists. In some places, however, the original lava and tuff were intruded by fine-grained to exceedingly coarse grained mafic rocks such as basalt, andesite, diorite, gabbro, pyroxenite, and possibly dunite. These intrusive dikes in the amphibolite may in part be feeders which supplied part of the pile of volcanic rocks. Great diversity in grain size of the dikes, even in the same exposure, is a common feature and may partly result from the dikes being formed under different conditions during successively younger episodes of intrusion. The regional metamorphism of fine-grained lava, tuff, graywacke, and tuffaceous argillite caused new minerals to form; and the grain size of the resulting metamorphic rock commonly became coarser than that of the original rock. The same metamorphism of coarse-grained mafic intrusive rocks transformed original large pyroxene grains to nests of amphibole, biotite, and chlorite and changed olivine grains to serpentine with resultant lessening of grain size. The new minerals in both groups of rocks are nearly in equilibrium with the metamorphic environment. Thus, in one outcrop which exposes both the mafic lavas and the dikes, an immense variety of amphibole-bearing rocks can be observed. Excellent examples can be seen in Fairfield County on State Route 215 between Salem Crossroads and the border with Chester County. Where these parts of the amphibolite unit were also intruded by granite and the whole assemblage was subsequently intruded by rocks of a gabbro-syenite-lamprophyre association, the resulting complex is an unusual record of igneous and metamorphic activity. Such records are well exposed north of Chester along the line between Chester and York Counties and southeast of Leeds in Chester County.

Parts of the areas shown as "diorite-gabbro" on the geologic map of North Carolina (Stuckey and Conrad, 1958) resemble the amphibolite unit shown by us in South Carolina.

Where mafic lavas are thin and closely interlayered with sedimentary rocks the product of metamorphism is a strongly banded gneiss in which dark amphibolite alternates with biotite-quartz-feldspar rocks. Excellent examples of this assemblage are exposed along U.S. Route 21 in Fairfield County between Flint Hill and Ridgeway where interbedded mafic volcanic rocks, graywacke, and argillite have been metamorphosed into a succession of fine-grained amphibolites and biotite schists. Other examples are discussed in the description of the argillite unit.

ARGILLITE

Argillite is the principal rock type in the slate belt of South Carolina, but felsic and mafic volcanic rocks are also included in the argillite unit on the large geologic map because soil formed on them was not separately distinguished on the soil maps. The argillite unit consists of poorly bedded to massive argillite, well-laminated argillite, tuffaceous argillite, siltstone, and fine-grained graywacke. The argillite is commonly called slate, but cleavage is generally not well developed; true slate is scarce. Unweathered argillites are dark gray to blue and massive to thin bedded. They consist of fine-grained clastic particles—derived from rocks that bordered the basin in which the argillites were deposited—locally mixed with varied amounts of volcanic ash. A good deal of the argillite appears to have been deposited without direct volcanic contribution.

Analyses of the argillites show somewhat larger amounts of silica and alumina than are found in an average shale; therefore, we infer that the land waste from which the argillites were formed included much debris from chemically weathered rocks. Many metamorphic rocks in the Inner Piedmont belt also have about the same abundance of silica and alumina. Analyses of argillites listed by Sloan (1908, p. 262–264) include some highly aluminous hydrothermally altered rock from gold mines. Excluding these analyses, the argillites contain 52–75 percent silica and 15–24 percent alumina. Crickmay (1952, p. 32) gave analyses of argillites metamorphosed to phyllite and schist in the Little River Series in Georgia—a southwestward extension of the Carolina slate belt of South Carolina—that show from 60–71 percent silica and 15–24 percent alumina.

The argillite unit also contains some coarse-grained material including quartzite and conglomerate. Quartzite is shown on the large geologic map (Overstreet and Bell, 1965) and is discussed separately below.

Gray-white layers of carbonate rock as much as one inch thick have been observed in drill cores taken from the argillite unit of the Carolina slate belt in Richland and McCormick Counties (H. S. Johnson, Jr., written commun., 1960). The carbonate rock was described by Johnson as apparently being sedimentary in origin. Johnson expressed the opinion, which we share, that carbonate beds are more common in the argillites than the weathered outcrops disclose and that beds of limestone as much as a few feet thick may be present.

Volcanic rocks such as felsophyre, rhyolite and andesite agglomerates, breccias, tuffs, and flows, and massive to amygdaloidal basalt flows are interbedded with and grade into the epiclastic rocks of the argillite unit. Although their distribution is not shown, these volcanic rocks form a large part of the argillite unit.

A thick sequence of light-colored felsic tuffs, flows, and agglomerates underlies the argillites between Camden and White Oak Creek in Kershaw County and along the county line between Kershaw and Fairfield Counties southwest of Wateree Pond. These rocks contain phenocrysts and fragments of feldspar as much as one-eighth of an inch across, whispy sigmoidal platelets of dark material as much as 4 inches long and three-eighths of an inch thick that may be fragments of shale, and sparse round quartz pebbles as much as one inch across. The felsic volcanic rocks in the argillite unit are commonly massive and flinty, and they break with conchoidal fracture. At places the rock is shattered in narrow zones. In the vicinity of White Oak Creek and to the southwest of Wateree Pond, schistose phases of the felsic volcanic rocks were observed in which feldspar and quartz phenocrysts are in a silky sericite-rich groundmass. Except for areas too small to show on the large geologic map (Overstreet and Bell, 1965), these schistose phases of the felsic tuffs are mapped as part of the muscovite schist unit (table 3) of the Carolina slate belt.

The felsic volcanic rocks in the argillite unit in Kershaw County are intruded by gabbro dikes which do not occur in the overlaying argillites. The dikes are stratigraphically significant because they indicate an unconformity between the top of the felsic volcanic rocks and the overlying argillites.

Near the center of the belt of argillite, along the boundary of Edgefield and Greenwood Counties, a thick sequence of felsic volcanic rocks was observed by W. T. McCutchen (H. S. Johnson, Jr., written commun., 1960). The stratigraphic significance of the felsic volcanic rocks in this area, however, is not certain.

Foliated felsic volcanic rocks containing round quartz granules and fine-grained felsic-lava fragments are exposed in Saluda County on the west side of the Saluda River at Kempsons Ferry Bridge. The relation of these volcanic rocks to the argillites in Saluda County is not known.

Mafic volcanic rocks, probably mainly andesitic in original composition, are rather common in the argillite unit. At most exposures the mafic volcanic rocks are thoroughly weathered to a massive punky mustard-colored to dark-maroon-red saprolite. The massive character is the most distinctive feature of this saprolite. Mafic volcanic rocks were shown by Heron and Johnson (1958) in the core of an anticline in the argillite at the east end of Lake Murray in the Irmo quadrangle. Heron and Johnson stressed that the mafic rocks are interbedded with argillite and quartz-sericite phyllite and that the boundary between the mafic volcanic rocks and other rocks of the slate belt in the Irmo quadrangle must be arbitrarily drawn. Elsewhere in the argillite unit—as in Kershaw County between Camden and White Oak Creek, in Chester County north and northwest of Great Falls, in Saluda County northwest of Batesburg, and, as observed by W. T. McCutchen (H. S. Johnson, Jr., written commun., 1960), in Edgefield County east of Brunson Crossroads and north of Pleasant Lane—mafic volcanic rocks form layers a few feet to a few hundred feet thick in the argillite. Probably there are many other occurrences of mafic volcanic rocks in the argillite unit, but they appear to be a subordinate part of the unit in South Carolina.

Bedding in the argillite unit can most easily be seen in the least metamorphosed argillites; it is poorly defined in the felsic and mafic breccias, agglomerates, and flows. Except at a few places, most of the felsic and mafic tuffs are poorly bedded. At many places the rocks are uncleaved, but fracture cleavage, without recrystallization, is conspicuous in other parts of the argillite. The fracture cleavage may be an axial-plane cleavage, because the trace of the cleavage on bedding planes is essentially parallel to the axes of nearby folds; but it may also be a pervasive regional cleavage unrelated to local folds. Kesler (1936, p. 40) commented that slaty cleavage crosses the bedding at various angles throughout the slate belt, but in the vicinity of Columbia, S.C., he rarely observed this relation. With growth of chlorite and sericite in the planes of fracture cleavage, a foliation is produced which tends to obscure bedding, particularly where foliation and bedding do not coincide. Foliation also resulted from mimetic crystallization of mica and quartz parallel to bedding, particularly near the margin of the argillite unit and wherever the metamorphic grade of the argillite was locally raised. Heron and Johnson (1958) stated, that the regional foliation in the argillites in the Irmo quadrangle, S.C., is nearly everywhere parallel to bedding; McCauley (1960) observed that foliation parallels bedding in Newberry County; and Johnson and McCauley showed us many convincing examples of foliation parallel to bedding in Fairfield and Newberry Counties. Elsewhere in the belt, however, as along the border between Fairfield and Kershaw Counties, we have seen foliation athwart the bedding. The relative proportions of coincident and crosscutting foliation have not been assessed, but we think that regional trends of bedding in the slate belt cannot be inferred with certainty on the assumption that foliation is generally parallel to bedding.

MUSCOVITE SCHIST

The muscovite schist is a metamorphic unit. It consists of muscovite-chlorite schist, sericite-quartz schist, muscovite-biotite-quartz schist, schistose to massive felsic volcanic rocks, and minor amounts of schistose of granite, chlorite schist, and hornblende schist. It occurs as bands 2–4 miles wide along the north and south edges of the argillite unit. Rocks of the muscovite schist unit also occur as small bodies within the argillite. The common position of broad bands of the muscovite schist unit between the argillite and neighboring belts of higher grade metamorphic rocks we interpret to be the result of progressive regional metamorphism of the rocks of the Carolina slate belt. The muscovite schist unit was probably formed before granite plutons were emplaced in the Carolina slate belt, and it is not the result of contact metamorphism.

Many layers of felsic volcanic rocks occur within the muscovite schist unit. In fact, there is probably a higher proportion of felsic volcanic rocks in the muscovite schist unit than in the equivalent but less metamorphosed argillite unit. This is because the regional metamorphic zones are not coincident with the strike of stratigraphic units but transgress the probable unconformity between overlying argillites and the underlying felsic volcanic rocks. Along the north side of the slate belt, a large part of the felsic volcanic rocks occur in the muscovite schist unit; whereas along the south side of the slate belt, the felsic volcanic rocks are commonly in the argillite unit. Quite possibly the felsic volcanic rocks on both sides of the belt are the result of the same volcanic disturbance.

Quartz veins are common in the muscovite schist and produce notably gravelly soils in northern Lexington County, southern Newberry County ("stone-hill section"), and Saluda County. Some of the quartz float in Newberry County doubtless comes from muscovite quartzite exposed north of the argillite (McCauley, 1960).

QUARTZITE

Small patches of quartzite—including muscovite, pyrophyllite, and kyanite quartzite—occur in the Carolina slate belt, as shown on the geologic map (Overstreet and Bell, 1965). Quartzite may be more common in the slate belt than has been reported in the literature. McCauley (1960) stated that muscovite quartzite, included in the muscovite schist unit on the geologic map, is the dominant rock type north of the argillite unit in Newberry County through an area a mile wide. Siliceous rocks, possibly quartzite, are exposed on the southern shores of Lake Murray (H. S. Johnson, Jr., oral commun., 1960). Quartzite at the border between Edgefield and Aiken Counties extends westward about 3 miles to the Savannah River where it forms a shoal. On the Georgia side of the river, the quartzite thickens into a large mass (R. G. Schmidt, oral commun., 1960). Stuckey and Conrad (1958, p. 27) described conglomerate in the slate belt in Chatham County, N.C., consisting of well-rounded quartz pebbles less than an inch in diameter that form several lenticular beds from a few inches to 250 feet thick in felsic tuff. The beds are exposed over a distance of 15–20 miles southwest of Siler City. Similar quartz conglomerates have not been found in South Carolina in the slate belt, although rounded quartz pebbles occur in felsic agglomerates in Kershaw County. At Graves Mountain, in Lincoln County, Ga., near the South Carolina boundary, quartz-pebble conglomerate (Hurst, 1959, p. 11) occurs interbedded with felsic pyroclastic rocks of the Little River Series. The massive quartz-rich rock which forms the heights at Graves Mountain and with which the conglomerate is interbedded was called quartzite by Crickmay (1952, p. 31) but was said by Hurst (1959, p. 5) to be felsic volcanic rock. Evidently quartz conglomerate is locally interbedded with felsic volcanic rocks in the slate belt in the three States.

The distribution of quartzite in the Carolina slate belt is similar to the distribution of quartzite in the metamorphic rocks between the slate belt and the Brevard belt. Quartzite in the Piedmont of South Carolina is, therefore, not restricted to a few narrow stratigraphic zones.

QUARTZ-MICROCLINE GNEISS

Quartz-microcline gneiss was described by Heron and Johnson (1958) from exposures in the spillway of the Dreher Shoals Dam on the Saluda River near Irmo, Lexington County. At that locality the rock is a fine-grained banded and lineated gneiss consisting of equally abundant quartz and microcline accompanied by 6 percent biotite and chlorite, 3 percent muscovite, and 1 percent plagioclase. Discontinuous small masses of hornblende gneiss occur within the main mass of quartz-microcline gneiss. Western extensions of the gneiss preserve the strong banding seen at the dam but become less quartzose and more granitic in composition. Rock shown on the geologic map (Overstreet and Bell, 1965) as quartz-microcline gneiss in Edgefield

County was noted by R. G. Schmidt (oral commun., 1960) to be similar in mode of occurrence and in radioactivity to the rock at Dreher Shoals Dam, but some of the rock in Edgefield County is massive two-mica granite.

Argillite in contact with the gneiss at the Dreher Shoals Dam was described by Heron and Johnson (1958) as containing garnet, kyanite, and staurolite. The metamorphic grade of the argillite decreases across strike away from the contact. R. G. Schmidt (oral commun., 1960) pointed out that the strongly gneissic rock at Dreher Shoals Dam is less metamorphosed than the massive granitic rock in Edgefield County, and he suggested that changes in the character of the quartz-microcline gneiss from the Dreher Shoals Dam to Edgefield County are related to the degree of metamorphism. Thus, the rock of Dreher Shoals Dam may be a less metamorphosed stratigraphic equivalent of that in Edgefield County, and both rocks may have formed from metamorphosed argillites.

INTRUSIVE ROCKS

MAFIC DIKES

The oldest intrusive rocks in the Carolina slate belt are mafic dikes that cut the amphibolite and felsic volcanic rocks but do not intrude the younger parts of the argillite and muscovite schist units. These mafic dikes are not shown individually on the large geologic map (Overstreet and Bell, 1965). Some of the areas shown as containing mafic dike swarms, however, may include these oldest intrusive rocks, particularly those areas within the Carolina slate belt. Areas of mafic dike swarms are most common in the Charlotte belt and are described with rocks of that belt.

Mafic dikes in the felsic volcanic rocks of the slate belt are well exposed along State Route 97 about a mile southeast of the contact between argillite and granite in Kershaw County. The dikes strike N. 30°–40° E. and dip 70°–75° NW. toward the granite. Chilled borders within the dikes have long thin pseudomorphic crystals oriented parallel to the walls of the dike. The crystals plunge about 15° NE. toward the granite in the direction of dip of the enclosing felsic volcanic rocks. The crystals consist of aggregates and plates of biotite that probably resulted from alteration of pyroxene(?), and the resulting metamorphosed rock has a superficial resemblance to biotite-rich lamprophyre associated with syenite dikes elsewhere in South Carolina. These mafic dikes are not lamprophyre, and they do not occur in the granite. They appear to have been folded when their host was folded; hence, the orientation of the pyroxene(?) needles, like the orientation of the dikes in which they occur, is rotated from its original attitude. Inasmuch as the granite has had very little metamorphic effect on the felsic volcanic rocks and on the argillites, it is likely that the alteration of the pyroxene(?) crystals in the dikes is related to a regional metamorphism predating or accompanying the emplacement of the granite.

Mafic dikes, possibly of andesite, occupy vertical fractures trending N. 30° E. and N. 50° W. in felsic volcanic rocks exposed at Kempsons Ferry Bridge in Saluda County. The dikes are offset along later fractures and are foliated harmoniously with the felsic volcanic rocks.

Similar mafic dikes have not been observed either in the argillites that overlie the felsic volcanic rocks in Kershaw County or in the argillite south of Kempsons Ferry Bridge in Saluda County. No mafic dikes were found by us in the argillite unit of the Carolina slate belt exposed along hundreds of miles of roads traversed in Chesterfield, Kershaw, Richland, Saluda, Greenwood, and McCormick Counties. Mention of a mafic dike in argillite was made by Smith (1959, fig. 2), who observed a dike that strikes about N. 80° W. in sericite phyllite at the Landrum mine about 4 miles east of Pleasant Lane in Edgefield County. Pardee and Park (1948, p. 119) described dikes in sericite schist at the Dorn mine on the north side of McCormick in McCormick County. The dikes at the Dorn mine are probably related to nearby conspicuous circular intrusives of gabbro and syenite and are thus considerably younger than the argillite. The relations of the dike in Edgefield County are unknown.

Biotite metagranodiorite and hornblendite were shown by Heron and Johnson (1958) in felsic slate-belt rocks in Lexington County. The biotite metagranodiorite occurs as pods in shear zones. The pods occupy 10–20 percent of the volume of the shear zone and seem to us more likely to be pseudoigneous rocks of metamorphic origin than dike rocks. The hornblendite is a dark medium-grained equigranular rock composed of 70 percent hornblende, 24 percent chlorite, 4 percent epidote, and 2 percent albite. The epidote and chlorite have formed from the hornblende. Instead of a sharp contact, the body of hornblendite is bounded by a zone of interlayered felsic volcanic rocks. Heron and Johnson considered that the composition of the hornblendite indicates an original intrusive pyroxenite. The contacts, however, suggested to them that the unit may be a series of mafic layers in the slates. We think that their conclusion based on composition is the most probable explanation and that the body of hornblendite was originally a pyroxenite dike younger than the argillite unit. The composition and layered ("onion-skin") contacts of the hornblendite are reminiscent of the hydrothermally altered members of the young group of gabbro, syenite, and related rocks discussed on page 39.

A group of posttectonic mafic dikes form conspicuous circular masses along the northern edge of the Carolina slate belt. This group, to which the dikes at the Dorn mine and the hornblendite in Lexington County are probably related, is described under the subsection "Charlotte belt."

FELSIC PLUTONS

The largest masses of intrusive rock in the Carolina slate belt are the granite plutons in Chesterfield, Kershaw, Lancaster, Fairfield, Richland, Saluda, and Edgefield Counties. These granites intrude the argillite unit as well as the older units of the slate belt and contain inclusions of their hosts.

Some of the granite plutons in the slate belt have been quarried, and the rocks in and about the quarries were described by Watson (1910, p. 172–205) and by Sloan (1908, p. 167–225). Short descriptions of several granite masses were given by Kesler (1936), Derby (1891, p. 206), Mertie (1953, p. 19–20, 25), and McCauley (1960). We have not attempted a rigid petrographic classification of the unnamed granites in South Carolina. Instead, a classification of granites based on grain size or on texture of the rocks as described in the texts accompanying the county soil maps seems more satisfactory for this report. The unnamed granites have been classed as coarse-grained, fine-grained, porphyritic, and undivided granite on the large geologic map (Overstreet and Bell, 1965). The reader is referred to the reports by Watson (1910) and by Sloan (1908) for particulars about the quarried granites of South Carolina, and to the description by Kesler (1936) for a discussion of the contact zones of granite in the slate belt. Only the notable megascopic features of some of the plutons are described below. It is evident, however, from the reports of Watson and Sloan that the commercial granites are less calcic in the eastern part of the State than in the western part. Possibly, the circular plutons that cut the argillite unit of the Carolina slate belt are the most potassic of the granite bodies in South Carolina.

Granite plutons that have circular to oval plans are conspicuous features of both the Carolina slate belt and the Charlotte belt. The perfectly formed circular pluton at and southwest of Winnsboro in Fairfield County is the finest example. The rock is coarse-grained biotite granite and has fine-grained selvages in which quarries have been opened. Locally the rock is a hornblende granite rich in sphene, as at a point about a mile south of Winnsboro on U.S. Route 321 (Watson, 1910, p. 189). The granite is massive and has local strong marginal flow banding. Inclusions of the wallrocks at least 100 feet in length are abundant near the rim of the pluton, and they are oriented parallel to the contacts. The plan of the pluton, the attitude of the pluton's contacts, and the orientation of inclusions show that the granite mass has the shape of an inverted tear drop whose northern and western walls dip inward more steeply than the southern and eastern walls. The attitude of many of the inclusions indicates upward and outward flowage of the granite from the small end of the tear drop.

The strike and dip of joints in the granite are consistent with the circular plan of the pluton. Watson (1910, p. 186–188) reported that the conspicuous vertical joint in the quarry at Rion strikes north and that the conspicuous vertical joints at the Anderson Quarry on the northwest edge of the pluton strike N. 20° E., N. 35°–40° E., N. 45°–50° W., N. 65° W., and N. 80° W. The north-trending joint at Rion and the northwest- to west-northwest-trending joints at Anderson Quarry are radial joints. The northeast-trending joints at Anderson Quarry are tangential joints. Radial joints at Anderson Quarry may contain aplite or simple pegmatite. At one place cited by Watson, the joint trending N. 65° W. is filled with a multiple dike composed of alternate bands of aplite and pegmatite. The perfect orientation of the radial and tangential joints and the fact that the radial joints opened to receive aplite and pegmatite is interpreted by us to show that the granite pluton was emplaced late in the tectonic history of the region. It is virtually undeformed, and the joints are cracks induced by cooling.

The wallrock of the Winnsboro pluton is locally brecciated, and the granite has entered the fractures. In the brecciated areas, even small fragments of wallrock are intricately ruptured by and threaded with granite. There seems to have been little or no rotation of the displaced blocks of wallrock in the brecciated zones, but within the pluton the inclusions plunge down the dip of the flow banding. Inclusions in the pluton match in lithology the rocks of the adjacent walls; thus, there was no large-scale turbulent transport of fragments plucked into the granite. Where the granite is in contact with felsic rocks of the Carolina slate belt, as near the boundary between Fairfield and Richland Counties, it contains angular inclusions of sericite schist and felsic tuff. Where the granite intrudes amphibolite of the slate belt in the vicinity of Browns Bridge, it contains slabs of biotite-hornblende schist and diorite. Where the granite is in contact with rocks of the Charlotte belt between Winnsboro and Anderson Quarry and southeast of Anderson Quarry, it contains swarms of inclusions of biotite schist, amphibolite, kyanite quartzite, kyanite-muscovite schist, and feldspar gneiss. The inclusions show very little effect of contact metamorphism, and what effect they do show is retrogressive. The inclusions of felsic tuff and sericite schist are unaffected.

Kyanite in the quartzite inclusions is retrogressively metamorphosed to sericite (Overstreet, Overstreet, and Bell, 1960), and some of the hornblende in inclusions of amphibolite is converted to biotite. It thus appears that the granite at Winnsboro has had little effect, other than mechanical, on its wallrocks.

The circular pluton west of Kershaw in parts of Kershaw, Lancaster, and Fairfield Counties also is an inverted tear-drop-shaped granite mass which has produced scant alteration of its wallrocks. At the eastern and southern contacts of the granite, the argillites of the Carolina slate belt are only slightly metamorphosed. Magnetite is formed in the argillites as far as half a mile from the contact, and biotite is present about 100 yards from the contact. Scattered porphyroblasts of potassium feldspar are formed in the argillites within a foot of the contact. Microscopic clastic texture of the argillite was found by Kesler (1936, p. 35) to be recrystallized adjacent to the granite.

The wallrocks of the pluton are in some places crosscut by the contact and are in others parallel to the contact. The general attitude of the wallrocks for distances of several thousand feet to several miles beyond the contact conforms to the outline of the granite, and inclusions for several thousand feet inside the rim of the pluton likewise are oriented parallel to the contact. Bedding and cleavage in the inclusions and wallrocks dip steeply inward toward the center of the pluton. It is possible that the folds producing these steep centripetal dips close to the contact are overturned away from the granite, and they give way farther from the contact to the normal attitudes associated with a large anticline breached by a pluton.

A small circular pluton of coarse-grained granite is exposed on both sides of the Broad River in Richland County. The rock was described by Heron and Clarke (1958, p. 71–75) as a porphyritic metagranodiorite that is intrusive into a felsic variety of the slate.

The elongate pluton of biotite granite in Saluda County between Batesburg and Clouds Creek has considerable variation in texture and color, but it is distinctly porphyritic throughout its western half and its northern end (R. G. Schmidt, oral commun., 1960; Watson, 1910, p. 200–201). Phenocrysts in the porphyritic granite are generally very distinctive, being round to oval crystals of potassium feldspar as much as 2 inches in diameter. A few feldspar phenocrysts are square in cross section. Watson (1910) stated that both orthoclase and microcline are present and that the orthoclase is partly intergrown with oligoclase. About $\frac{1}{8}$–$\frac{1}{4}$ inch inside the round feldspar phenocrysts, trains of biotite inclusions parallel to the rims can be seen. Much coarse-grained opaque blue quartz is in the groundmass. Fine-grained diorite and hornblende-biotite schist form small apparently random inclusions in the granite. An ill-defined lineation of the large phenocrysts in a plane trending N. 75° E. was noted by us at several localities; but the plunge of the phenocrysts could not be observed, and the trend attributed to them is not matched by the random orientation of the inclusions. Watson (1910) observed partial granulation of quartz and feldspar grains and poor orientation of biotite flakes in the pluton.

The pluton apparently occupies the core of a fold in the argillite (R. G. Schmidt, oral commun., 1960). The trend of the pluton conforms closely to the strike of the wallrocks except at places on the southwestern side of the pluton where the cleavage in the rocks of the Carolina slate belt is distinctly inclined to the contact. Beds of mafic volcanic rocks, perhaps as much as several hundred feet thick, are interlayered with argillite on opposite sides of the pluton. Inasmuch as the small inclusions of diorite and hornblende-biotite schist in the granite do not resemble the wallrocks, there might be some doubt that the granite is intrusive into the slates; but we think that the wallrocks show effects of contact metamorphism. Just west of Asbill Pond along the northwestern contact of the granite, we saw randomly oriented small plates of mica in the saprolite of cleaved mafic tuff. The plates of mica, seemingly muscovite, are poikiloblastic. We interpret the texture and structural relations of the mica as indicating that the plates of muscovite are porphyroblasts formed in the wallrock during emplacement of the granite.

A distinct oval pluton of pink to gray medium-grained closely fractured quartz-rich biotite granite was observed by W. T. McCutchen (H. S. Johnson, Jr., written commun., 1960) in felsic volcanic rocks of the argillite unit in the extreme northwestern corner of Edgefield County. It extends a short distance into McCormick County where it is in contact with mafic volcanic rocks in the argillite unit. No contact-metamorphic effects between the granite and its wallrocks were seen by us. The rocks in the argillite unit appear to dip away from the pluton.

CHARLOTTE BELT

METAMORPHOSED SEDIMENTARY AND VOLCANIC ROCKS

GRANITOID GNEISS

Granitoid gneiss is the principal map unit in the Charlotte belt. It includes gneiss, migmatite, and schist of the albite-epidote amphibolite facies and the amphibolite facies. Most of the rocks have a distinctive granitoid texture, but strong compositional layering in them suggests that they were probably derived from sediments, possibly from the Carolina slate belt. Some of the rocks in the granitoid gneiss unit, like the gneissic granodiorite exposed in York County, contain inclusions of other rocks and appear to be igneous in origin. The granitoid gneiss unit is the background from which other map units—such as granite, gabbro, syenite, and mafic dike swarms—could be separated on the basis of soil characteristics. The principal varieties of rock included in the granitoid gneiss unit are, in order of decreasing areal extent, fine-grained granular epidote-bearing feldspar biotite schist and granitoid gneiss; fine-grained granular feldspar biotite-muscovite schist; gneissic granite; granite; gneissic granodiorite; granular feldspar biotite-hornblende schist and gneiss; and, much less common, kyanite-muscovite schist, calc-silicate rock, kyanite quartzite, and sillimanite-muscovite schist. Hornblende-epidote-quartz-microcline gneiss observed by W. T. McCutchen (H. S. Johnson, Jr., written commun., 1960) in Edgefield County, east of the slate belt, is also included by us in the granitoid gneiss unit.

Strongly to weakly gneissic and even schistose bodies of migmatite are a common feature in the granitoid gneiss unit. The margins of these bodies are nebulitic: no sharp contact can be found between them and adjacent quartzfeldspar schists. In some gneiss that has minor compositional layering, variations among the layers are slight. These variations include differences in the relative proportions of quartz and feldspar, differences in grain size, presence or absence of muscovite or hornblende layers, and variations in the abundance of biotite. Strike and dip of the compositional layers appear to conform to the trends of foliation in adjacent schists. We interpret the layering to be partly of metamorphic origin and partly formed from original bedding.

Kyanite quartzite and kyanite-muscovite schist are scarce in the granitoid gneiss unit of the Charlotte belt. These rocks are present in Fairfield County, however, just southeast of the junction of State Routes 114 and 48, on State Route 48 about a mile northwest of the junction with State Route 269, and on State Route 70 about a mile southwest of Blackjack. At this last locality, kyanite-muscovite schist occurs as inclusions in an intrusive granite pluton. Kyanite-staurolite-muscovite schist occurs on State Route 91 about 3 miles southwest of Mount Carmel in McCormick County. Muscovite schist exposed near the center of Ninety Six in Greenwood County probably contains sillimanite and garnet. A narrow band of muscovite schist was observed by W. T. McCutchen (H. S. Johnson, Jr., written commun., 1960) to extend northeastward for approximately 4 miles from a point about 2 miles northeast of Colliers in Edgefield County. In this part of South Carolina, feldspar biotite schist and biotite-muscovite schist grade into gneiss and granitoid rocks (R. C. Schmidt, oral commun., 1960).

The average metamorphic grade of the granitoid gneiss unit is higher than that of the rocks in the Carolina slate belt, and local variations in grade are less pronounced. Metamorphic index minerals such as epidote, sphene, kyanite, sillimanite, staurolite, garnet, and chloritoid have been observed in the granitoid gneiss unit. Garnet, chloritoid, and kyanite are sparse and sillimanite is very scarce. The sparseness of these index minerals suggests that the rocks of the Charlotte belt have in only small areas been brought to higher metamorphic grade than the staurolite-kyanite subfacies of the amphibolite facies (Turner, 1948, p. 81–87). The commonness of sphene rather than rutile in the Charlotte belt suggests that the gneissic and schistose rocks never attained the metamorphic grade of the granulite facies (Ramberg, 1952, p. 72–75), although many of them have distinctly granoblastic (saccharoidal) texture.

Slightly metamorphosed rocks alternate with the higher grade granitoid gneiss. Thus, in Edgefield and McCormick Counties, gneisses are interbanded with sericite phyllite and argillite. In McCormick, Abbeville, Greenwood, Union, and York Counties, similar argillites, phyllites, and schists have been shown separately on the large geologic map (Overstreet and Bell, 1965) as representing rocks either of the Carolina slate belt or of the Kings Mountain belt. East of the slate belt granitoid gneiss, granite, and bands of argillite crop out in inliers exposed through the mantle of Coastal Plain sedimentary rocks. Granite and schist have been reached by wells that penetrate from 365 to 2,450 feet of Coastal Plain sedimentary rocks in eastern South Carolina (Siple, 1958, p. 67–68).

Much of the rock called granite in the South Carolina Piedmont probably represents metamorphosed and locally mobilized sedimentary rocks. A similar contention has been maintained for many years by Mertie (1953, p. 29–30; 1957) as a result of his studies of the accessory minerals in the granites of the Southeastern States. Large parts of the Charlotte belt consist of this material.

The granitoid gneiss unit of the Charlotte belt is commonly threaded by sharp-walled dikes of felsite, aplite, and fine-grained granite. Most of these dikes are less than a foot thick, but some of the granite dikes are at least several hundred feet thick. Locally, the granite dikes are sufficiently numerous and closely spaced so that the composite unit of dikes and host is best described as a breccia. Large metacrysts of potassium feldspar are sporadically present in the granitoid gneiss, particularly in the areas underlain by migmatite and in schist adjacent to migmatite. The metacrysts are rare in the sharp-walled dikes of felsite, aplite, and fine-grained granite. Where they do occur in the dikes, as around Leeds in Chester County, some have grown across the contact into the wallrock.

Pegmatite dikes in the granitoid gneiss unit are small and rare. They are mineralogically simple and consist mainly of intergrowths of microcline and quartz. Along strike and downdip the proportions of the two minerals may change abruptly from masses of pure feldspar to veins of pure quartz. Graphic intergrowths of quartz and feldspar occur as isolated pods in the pegmatite dikes or quartz veins. Muscovite is seldom present except in the pegmatite dikes in the part of the Charlotte belt southeast of the slate belt. At the few places where muscovite was observed, it forms randomly oriented books and plates mostly less than one-quarter of an inch across but locally as much as 2 inches across. The abundance of muscovite-bearing pegmatite dikes is greater in the granitoid gneiss unit southeast of the slate belt than in the other parts of the Charlotte belt.

A few large bodies of pegmatite were observed in the Charlotte belt. They are biotite-microcline pegmatite dikes rimmed with vermiculite and appear to be syenite pegmatites associated with bodies of late gabbro and syenite discussed below.

Veins composed of quartz, or of quartz and other minerals, occur in the granitoid gneiss unit of the Charlotte belt. The varieties of veins observed include quartz, hematite-sheathed quartz, quartz-feldspar, quartz-epidote, quartz-feldspar-epidote, feldspar-epidote, quartz-sericite, and quartz-sulfide. The veins, particularly the epidote-bearing veins, tend to occupy localized zones of fracture; and wherever found, they crosscut the foliation of the gneiss and schist. The veins only rarely conform to the layering of the host, in striking contrast to the common concordant attitude of quartz veins in the Inner Piedmont belt. Most of the veins are less than 4 inches thick, and many are mere coatings on joints; a few milky quartz veins, or quartz-sulfide veins, reach 40 feet in thickness. Gold-bearing quartz veins have been found in the Charlotte belt, but most gold-bearing veins or lodes reported by Sloan (1908, map) and shown in plate 3 are in the Kings Mountain and Carolina slate belts.

MICA GNEISS

The mica gneiss unit of the Charlotte belt consists of fine- to medium-grained layered biotite and hornblende gneisses and schists and associated granitic rocks that resemble in lithology and metamorphic grade the granitoid gneiss unit of the Charlotte belt. The mica gneiss unit is, however, separated from the granitoid gneiss unit by the band of amphibolite which we infer to be identical with the basal unit of the Carolina slate belt in Fairfield, Chester, and York Counties. We conclude, therefore, that the mica gneiss unit is stratigraphically younger than the granitoid gneiss unit and that it includes the same stratigraphic units that make up the argillite and muscovite schist units of the Carolina slate belt.

The mica gneiss, like the granitoid gneiss, is an undifferentiated background unit of gneisses and granite from which distinctive masses of mafic rock, schist, and granite were separated.

Swarms of mafic dikes may be fairly common in the mica gneiss unit in Lancaster and York Counties. The texts with the soil maps comment on the abundance of diorite and mafic porphyries in the area; however, the soils shown on the county maps do not fully reflect the distribution of the mafic dike swarms. Lieber (1858a, p. 33–34, map) and Hammond (1883, map) showed swarms of mafic porphyries in York County, and Lieber remarked on their wide general distribution and hornblendic character. The main areas that Lieber and Hammond showed as underlain by mafic porphyries are large kidney-shaped bodies of gabbro which intrude through the older dike swarms. We have added some areas shown by Lieber as aphanitic porphyry to the few areas of mafic dike swarms in York County. The linear shape of the areas of porphyry as shown by Lieber contrast strongly to the irregular areas depicted on the county soil maps and suggest to us that some bedded mafic flows or tuffs are also present.

The probability that mafic dike swarms and possibly mafic flows and tuffs are common in the mica gneiss unit of the Charlotte belt is supported by evidence from the geologic map of North Carolina (Stuckey and Conrad, 1958, map). The diorite-gabbro unit on that map projects into Lancaster and York Counties. At many places where we have examined this unit in Cabarrus County, N.C. (Bell and Overstreet, 1959), it contains swarms of mafic dikes.

INTRUSIVE ROCKS

GRANITE

The major bodies of granite in the State are in the Charlotte belt. Some, possibly much, of the rock shown separately on the large geologic map (Overstreet and Bell, 1965) as granite may be similar to some of the undifferentiated granite included with the granitoid gneiss unit. A distinctive oval pluton in Chester County, however, is one of the best examples of intrusive granite in the belt. It consists of gray coarse-grained porphyritic biotite-muscovite granite with a fine-grained marginal facies. The pluton is separated from a less regularly shaped body of coarse-grained granite in Union County by a thin screen of schist. The pluton in Chester County occupies the core of a syncline and contains inclusions oriented parallel to its walls and plunging inward toward the center of the mass. The pluton is shaped like an inverted tear drop and thus resembles the plutons in Fairfield and Kershaw Counties.

A unit of granitic rock, named the Yorkville Quartz Monzonite, occurs in both the Charlotte and Kings Mountain belts. It is described with rocks of the Kings Mountain belt.

Dikes of granite, aplite, and pegmatite intrude the different varieties of granite shown on the geologic map (Overstreet and Bell, 1965). The pegmatites in the granites, like those in the granitoid gneiss unit, are commonly small, simple, and free of muscovite. In fact, no commercial muscovite pegmatites have been found in the Charlotte belt despite the presence of an immense amount of granitoid rock.

Diorite, quartz diorite, and granodiorite occur with some granites as marginal phases and as members of the complex series of mafic dikes found in the Charlotte belt and Carolina slate belt. Many of the granite bodies are sharply fractured, and the fractures are filled with mafic dikes of the young gabbro sequence, as, for example, southwest of Chester in Chester County and west and northwest of York in York County.

Many of the small granite bodies shown in Chester, Newberry, Greenwood, and Abbeville Counties may upon careful field investigation prove to be parts of a few large granite masses. Nevertheless, granite masses approaching in size the dimensions of the largest granite bodies shown on geologic maps of North Carolina (Stuckey and Conrad, 1958, map), Virginia (Stose, 1928), and Georgia (Stose and Smith, 1939) are unlikely. Detailed mapping will undoubtedly show that there are no immense batholiths like those described for South Carolina and adjacent states by Keith (1923, p. 321) and shown on the geologic map of the United States by Stose and Ljungstedt (1932). Examination of the different geologic belts in the State, which is equivalent to studying a vertical section of the earth's crust below the slate belt, gives no support to the concept that the plutons in the Charlotte belt and Carolina slate belt are cupolas of an immense batholith hidden at depth (Kesler, 1936, p. 39). If anything, the granite bodies decrease in size with increasing depth.

The areas of the well-defined granite plutons in the Charlotte belt and in the Carolina slate belt attain batholithic dimensions, but their shapes are not the shapes of batholiths. The large plutons are between 100 and 200 square miles in area; thus, they exceed the minimum area of batholiths, which is said by Daly (1933, p. 113) to be 40 square miles. The walls of batholiths diverge downward, but the walls of the plutons in South Carolina converge downward. Plutons of the Charlotte belt are structurally controlled and are located in folds.

They also appear to be localized near the contact between granitoid gneiss of the Charlotte belt and amphibolite and argillite of the slate belt. They generated multiple fractures in their slate-belt ceiling. In the Inner Piedmont belt, where the majority of the plutonic rocks in the State are exposed, few large bodies of granite are found; but countless veins, sills, sheets, and small masses of granite are present. Even the two large granites shown in the Inner Piedmont belt in reality consist of innumerable sheets and layers of granite interlaminated with septa of schist and gneiss. They are not homogeneous masses of granite. It is as if the granitic material was formed as myriads of little granitic filaments throughout the gneiss at and below the level of the Inner Piedmont belt and Charlotte belt now exposed. The granitic material seemingly moved upward from these many small centers to coalesce and produce the plutons in the low-pressure–low-temperature environment against the fractured slate-belt ceiling. The oval and circular plutons may be diapiric.

GABBRO, PYROXENITE, AND NORITE

Distinctive masses of gabbro intrude the granite and granitoid gneiss of the Charlotte belt, the sedimentary rocks of the Carolina slate belt, and the schists of the Kings Mountain and Inner Piedmont belts. These gabbros are of two ages and are distinguished by their form and mode of occurrence. The older gabbros are most common in the Kings Mountain, Inner Piedmont, and Blue Ridge belts. They are commonly strongly foliated on their margins, boudinaged, folded, metamorphosed, and locally intruded by and included in granite gneiss (Overstreet, Theobald, and Cuppels, 1953, p. 25; Overstreet and Griffitts, 1955, p. 572–573).

In contrast, the younger gabbros are coarse grained and massive. They are most common in the Carolina slate belt and in the Charlotte belt, although gabbroic rocks of similar appearance and of possible identical age and relations occur in areas of hornblende gneiss in the Inner Piedmont and in the Blue Ridge. Some small areas, such as one near Iva, Anderson County, are shown as hornblende gneiss on the large geologic map (Overstreet and Bell, 1965) but may be gabbro. For many of these gabbro masses, particularly those in the Inner Piedmont belt, the available data on location, which are confined chiefly to descriptions of mineralogic localities for corundum and serpentine, are inadequate; thus the gabbros are not shown on the large geologic map.

The gabbro, pyroxenite, and norite unit shown on the large geologic map (Overstreet and Bell, 1965) is predominately the younger gabbro; the older gabbro is not separately shown. However, older gabbro predominates in the gabbro and soapstone unit in the Inner Piedmont.

The outline of most of the younger gabbro masses is circular or kidney shaped in plan. The large mass of gabbro near Ninety Six in Greenwood County may be several circular masses of gabbro that have coalesced into one irregularly shaped multiple intrusive. In Abbeville, Greenwood, and McCormick Counties, nine gabbro masses lie along a pronounced arc extending from the vicinity of Calhoun Falls to McCormick.

The areas where gabbro crops out are usually topographic depressions, the largest of which are at least 100 feet below the surrounding land surface. The immediately adjacent rocks commonly form low ridges which follow the outline of the gabbro body. Lieber (1860, p. 45) aptly described the topography as resembling a knot in a pine plank. At their contacts, and perhaps throughout, some gabbro masses consist of layers of mafic rock of different composition. The layers which give the rock an "onion-skin" effect, range from several tens to hundreds of feet in thickness. The symmetry of the layers is interrupted by displacement along fractures. Some of the fractures are occupied by dikes of diorite, diorite porphyry, syenite, syenite pegmatite, and biotite lamprophyre. "Onion-skin" contacts can be seen along the deep roadcuts of State Route 823 between Lott Creek and the Little River northeast of Mount Carmel in McCormick County where coarse-grained syenite is in contact with gabbro. The two rocks are cut by dikes of diorite and fine-grained syenite.

The younger gabbro in the Charlotte belt is a coarse-grained to very coarse grained rock which is typically massive and little serpentinized. In two areas, however—along the Savannah River south of State Route 72 in Abbeville County, and 1.9 miles southeast of Leeds in Chester County—outcrops of what may be the gabbro are thoroughly sheared and serpentinized. At a few places within the circular bodies of gabbro, knobby coarse-grained rough-textured gray to dark-brown boulders can be found; the boulders are rather feldspathic and resemble norite, and they give a sharp distinctive metallic note of good resonance when struck with a hammer. This rock may be the one that Lieber (1859, p. 14) referred to as "phonolith" and said is associated with soapstone, diorite, and minette in South Carolina.

The principal rock of the gabbro, pyroxenite, and norite unit is hornblende gabbro which grades in composition to hornblendite. The hornblende commonly has strong brown pleochroism and contains many relicts of diallage (J. F. McCauley, written commun., 1959) and of hypersthene, including bronzite. McCauley reported as much as 4 percent olivine in gabbro from the central part of the mass at Calhoun Falls in Abbeville County and 1 percent olivine in gabbro near the margin of the mass. The olivine is rimmed by diallage, partly replaced by hornblende. Alteration of the olivine to pyroxene and of the pyroxene to hornblende was thought by McCauley to be a late-magmatic process unrelated to regional metamorphism. In our opinion this gabbro was emplaced after the last regional metamorphism and could not have been effected by the metamorphism; thus, we concur with McCauley's interpretation.

Few of the gabbro bodies in South Carolina have been examined in detail; hence we do not know how completely late magmatic alteration has converted pyroxene and olivine to hornblende. Most of the gabbro bodies that we have examined in the Charlotte belt are hornblende gabbro and hornblendite derived from pyroxene gabbro and pyroxenite. Relict hypersthene is present in some of these rocks, and some of the intrusives probably were originally norite. Inasmuch as olivine is present in the gabbro and peridotite is associated with the gabbro, it is likely that some of the present hornblendite was peridotite. The kidney-shaped mass of hornblende hypersthenite (pyroxenite), hornblende-hypersthene peridotite, and olivine gabbro shown by Keith and Sterrett (1931, map) in the Inner Piedmont belt a few miles west of Patterson Springs, Cleveland County, N.C., may belong to this group of young intrusives; but we think that the elongate, seemingly folded, bodies of pyroxenite and soapstone shown by Keith and Sterrett in hornblende gneiss 4 miles south-southwest of Gaffney, Cherokee County, are related to the older gabbro. A small mass of talc schist associated with metapyroxenite and biotite pegmatite 1.9 miles southeast of Leeds in Chester County may be the altered equivalent of dunite that is related to the late gabbro sequence, but dunite has not been observed.

At some of the corundum localities mentioned by Sloan (1908, p. 150–154), particularly at the zircon-rich corundum deposits east of Iva near the Rocky River in Anderson and Abbeville Counties and at the locality in York County 12 miles northeast of York, the corundum may be in peridotite instead of in metamorphosed sedimentary rocks. The corundum was described as being in "hydromica slates," a term used by Sloan to include weathered ultramafic rocks, and the zircon was said to be in "feldspathic rocks." Possibly some of this feldspathic rock may be syenite associated with the gabbro and pyroxenite; however, the zircon-rich rock east of Iva is reported in the records of the U.S. National Museum (G. S. Switzer, oral commun., 1960) to be gneiss.

Dikes of diorite and diorite porphyry occur in various parts of York, Chester, Lancaster, McCormick, and Greenwood Counties (Lieber, 1858a, p. 35; 1860, p. 4). Some of these occurrences may be old dikes related to one or another of the igneous episodes represented in the Carolina slate belt, but those dikes that intrude gabbro at and southeast of Calhoun Falls and intrude syenite northeast of Mount Carmel are part of the young gabbro sequence.

Biotite-rich lamprophyre dikes were recognized and called minettes by Lieber (1858a, p. 49–52; 1860, p. 47) in York County at a point 6 miles northeast of York and in Abbeville County on the northern outskirts of Calhoun Falls. At the Calhoun Falls locality the dikes are related to the gabbro body. Dikes of minette were found by us in the syenite and gabbro northeast of Mount Carmel, McCormick County. Possible minette is exposed at the Dorn mine in the town of McCormick, McCormick County (Pardee and Park, 1948, p. 119), and is probably related to the mass of gabbro north of the town. Similar dikes cut syenite and gabbro in Cabarrus County, N.C. (Bell and Overstreet, 1959, p. 3), and appear to be genetically related to the gabbro and syenite.

A few thin pegmatite dikes composed of microcline, pale-green to colorless muscovite, and quartz have been seen in the gabbro, particularly in the mass on the southern outskirts of Rock Hill in York County. Few dikes are more than 18 inches thick. We interpret them to be very local potassic differentiates from the gabbroic magma; this view was earlier taken by Murdock and Hunter (1946, p. 8).

SYENITE

Syenite is associated with, and presumably is a differentiate from, gabbro bodies in McCormick, Union, and York Counties. The largest mass of syenite in the State is the augite syenite (G. H. Espenshade, oral commun., 1959) that forms the southwestern shoulder on the gabbro northeast of Mount Carmel. The coarse-grained gray rock forms bold outcrops. Elsewhere in the State the syenite forms inconspicuous outcrops and appears to be thin selvages in the gabbro. The pyroxene syenite in York County is dark red and forms small but conspicuous bouldery outcrops. Anorthosite was found by Robert Butler in 1961 in North Carolina adjacent to the York County syenite area (H. S. Johnson, Jr., written commun., 1962).

Zircon [1] was first described as an abundant accessory mineral in syenite in South Carolina by Lieber (1860, p. 29), who discussed the

[1] Zircon from syenite and syenite pegmatite in North and South Carolina has a distinctly lower hafnium-zirconium ratio than zircon from granites and gneiss. Hafnium-zirconium ratios were published by Mertie (1958, p. 16–22) for zircon from the syenite pegmatite at Zirconia, Henderson County, N.C., from probable syenite pegmatite from Iredell County, N.C., from syenite near Concord, Cabarrus County, N.C., and from "saprolite of granite gneiss adjacent to pegmatite at vermiculite mine" (a syenite pegmatite) near Tigerville, Greenville County, S.C. These ratios range from 0.017 to 0.021 by spectrographic methods and from 0.015 to 0.018 by X-ray fluorescence, and they average 0.018. The ratios in zircon from 26 samples of granite, gneiss, and schist in the Southeastern States range from 0.020 to 0.035 by spectrographic methods and from 0.020 to 0.031 by X-ray floures-

unusual abundance of zircon in minette and syenite in an area east of Iva near the Rocky River in Anderson County. We have not examined the accessory minerals in syenite from South Carolina, but we found that identical syenite in Cabarrus County, N.C., is rich in zircon. J. B. Mertie, Jr. (oral commun., 1959), informed us that the syenite in Cabarrus County contains more zircon than does any other of the hundreds of rocks that he has sampled in the Southeastern United States.

Syenite pegmatite consisting of microcline and biotite or vermiculite with little or no quartz is a coarse-grained differentiate from the gabbros. This pegmatite forms dikes found both within and some distance from the gabbro. Olson (1952, p. 20) described the wall zones of the syenite pegmatites at Zirconia, Henderson County, N.C., as being 15–20 feet thick and rich in vermiculite. He stated that the abundance of vermiculite does not result from reaction between the pegmatite and its host because thick vermiculite wall zones exist where the host is granitic gneiss. The syenite pegmatites at Zirconia are also remarkable owing to abundant accessory zircon. Biotite and vermiculite deposits in which accessory zircon is unusually abundant and in which pegmatites are found occur near Tigerville in Greenville County. Some, possiby most, pegmatite-cored vermiculite deposits elsewhere in the State may be syenite pegmatites and belong to the younger gabbro assemblage. The syenite pegmatite dikes are distinctly younger than the muscovite pegmatite dikes of the Inner Piedmont belt. Certain rare pegmatite bodies, such as the spodumene pegmatites in Cherokee County, may be related to this late sequence.

MAFIC DIKE SWARMS

The great number and variety of mafic dikes, locally aggregating into dike swarms, is a distinctive feature of the Charlotte belt. Only areas thought by us to contain mafic dike swarms and not individual dikes are shown on the large geologic map (Overstreet and Bell, 1965). The dikes can be correlated with several different igneous episodes by means of their crosscutting relations and their structural, textural, and metamorphic characteristics. The dike swarms are part of a widespread unit called diorite-gabbro on Stuckey and Conrad's (1958) geologic map of North Carolina.

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cence, and they average 0.025. As early as 1956, Gottfried, Waring, and Worthing (1956, p. 1700) showed that the hafnium-zirconium ratio in zircon from syenite at many localities is significantly lower than the ratio in zircon from granitic rocks. According to David Gottfried (oral commun., 1961), large zircon crystals from the Carolinas that are displayed in museums commonly have low hafnium-zirconium ratios. We think that the sources of these large crystals are principally the syenite pegmatites in Iredell and Henderson Counties, N.C., and in Greenville County, S.C.

Older dike swarms consisting of metamorphosed basalt, andesite, andesite porphyry, diorite, and diorite porphyry possibly were feeders for the effusive mafic rocks in the Carolina slate belt (Bell and Overstreet, 1959, p. 4). The old dikes are foliated and faulted and are widely cut by, and occur as included fragments in, the granites that cut the rocks in the slate belt. Some of these dikes are related to the mafic dikes that intrude felsic volcanic rocks in the slate belt. At most places in the Charlotte belt in South Carolina, the older dike swarms appear to cluster near the inferred unconformity between the amphibolite and muscovite schist units of the Carolina slate belt and the granitoid gneiss unit of the Charlotte belt; also, there are few dike swarms in the central part of the Charlotte belt. From these spatial relations we interpret a feeder association between the dikes and mafic volcanic rocks in the slate belt.

Dike swarms predominantly younger than effusive rocks in the slate belt and mainly younger than the granites are known and included in the unit in Abbeville, Greenwood, McCormick, and York Counties. These dike swarms include lamprophyre, diorite, diorite porphyry, gabbro, and pyroxenite of the younger gabbro sequence. Doubtless, in this same area, swarms of the old dikes also occur. Dike swarms of the two ages, however, cannot be shown separately on the large geologic map (Overstreet and Bell, 1965) with the available data.

Diabase dikes of Triassic(?) age are readily recognizable and are shown separately on the large geologic map. Some of the areas interpreted from the soil maps as dike swarms but not field checked, particularly those that tend to be alined in the directions common to the diabase dikes, may well be the outcrops of boulders of diabase that are localized along a dike.

KINGS MOUNTAIN BELT

The Kings Mountain belt of sericite schist, hornblende schist, and minor amounts of quartzite and marble is well defined in the central part of the mapped area. It extends southwestward from Kings Mountain in Cleveland and Gaston Counties, N.C., into Cherokee County, S.C., east of Gaffney. Thence it can be followed to Lowndesville in Abbeville County, S.C., and into Georgia. In Cherokee and York Counties, S.C., the Kings Mountain belt includes rocks described by Keith and Sterrett (1931, p. 4–6) as the Battleground Schist, Kings Mountain Quartzite, Blacksburg Schist, Gaffney Marble, and Bessemer Granite. Small parts of the Kings Mountain belt in Cherokee and York Counties include rocks mapped by Keith and Sterrett as Roan Gneiss and Carolina Gneiss. South and southwest of Chero-

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kee County, the Kings Mountain belt consists mainly of sericite schist and, locally, of kyanite muscovite schist which we think is an extension of the Battleground Schist. We infer that the continuation of the Kings Mountain belt in Elbert County, Ga., appears as hornblende gneiss on the northwestern side of a band of schist in the Little River Series (Stose and Smith, 1939, map). The relations of the rocks in the Kings Mountain belt to rocks in the Carolina slate belt in Chester and Union Counties seem to us most satisfactorily explained if all the units are considered to be part of an immense sequence of rocks that is separated from older rocks by a well-defined unconformity (table 4; pl. 1). The rocks of the Kings Mountain belt include a younger unconformity which can also be correlated with an unconformity in the slate belt (table 4). Correlation of individual stratigraphic units in the Kings Mountain belt, such as the Draytonville Conglomerate Member of the Kings Mountain Quartzite, with individual units in the slate belt, such as a particular quartzite layer, is not attempted. We, therefore, do not show on the large geologic map (Overstreet and Bell, 1965) the variety of formations to which the sedimentary and volcanic rocks around Kings Mountain have been assigned.

METAMORPHOSED SEDIMENTARY AND VOLCANIC ROCKS

HORNBLENDE SCHIST

The hornblende schist unit of the Kings Mountain belt consists of hornblende schist, hornblende gneiss, actinolite schist, chlorite schist, and marble. These rocks were formed by metamorphism of mafic effusive and intrusive rocks, graywacke, and calcareous sediments. The unit includes the formations in Cherokee and York Counties that Keith and Sterrett (1931, maps) called Roan Gneiss and Roan Gneiss closely injected by Bessemer Granite. Three miles south of Gaffney, several small bodies of soapstone, pyroxenite, and allied mafic rocks are included with the hornblende schist unit because they are too small to be shown separately.

The metamorphic grade of the hornblende schist unit ranges from the biotite-chlorite subfacies of the greenschist facies to the sillimanite-almandine subfacies of the amphibolite facies.

Much of the rock in the hornblende schist unit is evidently of igneous origin, and we believe that parts of the unit in southwestern York and eastern Cherokee Counties are correlative with the amphibolite unit of dominantly volcanic origin in the Carolina slate belt. The hornblende schist in western Union County, 4–6 miles southwest of Union, may also be mainly of igneous origin, particularly in the area where intrusive gabbro and syenite occur. The occurrence of marble near Musgrove Mill and Cross Keys (Johnson, 1958), coupled with the examples of amphibolite formed from dolomitic limestone cited by Kesler (1944, p. 770–771) for Cherokee County and by Clarke (1957) for Laurens County, indicates that some of the hornblende schist of both the Kings Mountain belt and the Inner Piedmont belt is derived from calcareous sediments.

SERICITE SCHIST

The sericite schist unit of the Kings Mountain belt consists principally of pyroclastic rocks, argillite, and graywacke metamorphosed to the greenschist facies generally and locally to facies of higher metamorphic grade. It is white, gray, or bluish-black sericite schist, sericite phyllite, quartz-mica schist, kyanite muscovite schist, sillimanite muscovite schist, biotite schist, and biotite gneiss. Some layers are graphite bearing. Discontinuous black, manganese-rich layers are commonly recognized in saprolitic exposures.

The sericite schist unit has three main parts: (1) a broad eastern part, including the Bessemer Granite, Battleground Schist, Draytonville Conglomerate Member, and Blacksburg Schist of Keith and Sterrett (1931, maps) in Cherokee and York Counties, (2) a narrow western part in Cherokee County, including the Blacksburg Schist, Kings Mountain Quartzite, and Gaffney Marble of Keith and Sterrett (1931, map), and (3) a southwestern extension of the Battleground Schist into Laurens, Union, and Abbeville Counties (Overstreet and Bell, 1960a).

The broad eastern part of the sericite schist unit is predominantly composed of sericite phyllite, sericite schist, quartz-mica schist, biotite schist, and graphite phyllite. Hornblende schist nearly surrounds the eastern part and separates it from the narrow western part of the sericite schist unit. More than half of the eastern part of the sericite schist unit was mapped as Bessemer Granite by Keith and Sterrett (1931, maps). Their Bessemer Granite was named from outcrops near Bessemer City in Gaston City, N.C., but they showed its broadest exposures in York County, S.C. Potter (1954, pl. 1) and Espenshade and Potter (1960, p. 72) found that the rocks called Bessemer Granite were mostly quartz-mica schist, hornblende gneiss, biotite gneiss, and biotite schist representing metamorphosed pyroclastic and sedimentary rocks, principally felsic volcanic rocks. According to W. R. Griffitts (written commun., 1960), Sterrett's notes for the area shown on the folio maps as Bessemer Granite indicate that he observed much the same rock types as those seen by Potter—namely, muscovite schist, biotite schist, and hornblende gneiss. Potter did not discover any extensive sheared granite and phyllonite, as had been described by Keith and Sterrett (1931, p. 4) and by Jonas (1932, p. 236–237), but he did observe that the metamorphic rocks were considerably sheared. He also found small bodies of massive to locally strongly sheared oligoclase tonalite in the schists. Keith and Sterrett considered the Bessemer Granite to be Precambrian in age; they thought that it intruded the ancient Precambrian Carolina and Roan Gneisses and was unconformably overlain on its west side by sericite schist of the Battleground Schist of Precambrian age and by Draytonville Conglomerate Member of Cambrian age. Jonas (1932, p. 237) regarded all the metamorphosed sedimentary and pyroclastic rocks in the Kings Mountain belt as Precambrian in age and as retrogressive and polymetamorphic in character. Potter (1954, p. 18) found no direct evidence for age or regional correlation of the metamorphic rocks in the Kings Mountain area, but he pointed out many similarities between the rocks at Kings Mountain and the rocks in the Carolina slate belt. He concluded that the rocks in the Kings Mountain belt and in the slate belt were equivalent in origin and stratigraphic position and were late Precambrian(?) or early Paleozoic(?) in age (Espenshade and Potter, 1960, p. 70). Potter thought the oligoclase tonalite was intrusive into its wallrocks. He stated that an unconformity existed between a unit made up of the oligoclase tonalite and its host rocks (the Bessemer Granite of Keith and Sterrett) and rather similar schists exposed to the west (the Battleground Schist of Keith and Sterrett). Potter emphasized lithologic similarities among the units called by Keith and Sterrett the Carolina Gneiss, the Roan Gneiss, the Bessemer Granite, and the Battleground Schist.

The many similarities between the Bessemer Granite of Keith and Sterrett and the Battleground Schist lead us for mapping purposes to combine them into the lithologic unit which we call sericite schist of the Kings Mountain belt. We think that the broad eastern part of this unit in Cherokee and York Counties is divided by an unconformity, as stated by Keith and Sterrett and by Potter. This unconformity is between the Battleground Schist and the Bessemer Granite of Keith and Sterrett and is the same unconformity that we recognize in the argillite and muscovite schist units of the Carolina slate belt. By this correlation the Battleground Schist, Kings Mountain Quartzite, Blacksburg Schist, and Gaffney Marble as defined by Keith and Sterrett are above the unconformity and are equivalent to the argillite and pyroclastic rocks of the Carolina slate belt that unconformably overlie the felsic tuffs intruded by metamorphosed mafic dikes. The schistose parts of the Bessemer Granite with narrow inclusions of hornblende gneiss, as defined by Keith and Sterrett and described by Potter, are equivalent to the felsic volcanic rocks and associated sediments that are intruded by mafic dikes. The Roan Gneiss, into which Keith and Sterrett thought the Bessemer Granite to be intruded, is shown as hornblende schist of the Kings Mountain belt on the geologic map (Overstreet and Bell, 1965) and is equivalent to the amphibolite unit of the Carolina slate belt. These relations are shown in table 4.

The term Bessemer Granite, originally proposed by Keith and Sterrett (1931, p. 4), is not used on the geologic map (Overstreet and Bell, 1965); but the distribution of the small bodies of oligoclase tonalite found by Potter (Espenshade and Potter, 1960, p. 72–73) is shown, and the rocks are discussed below.

The narrow western part of the sericite schist unit in Cherokee County consists of the Blacksburg Schist, Kings Mountain Quartzite, Gaffney Marble, and Carolina Gneiss of Keith and Sterrett. According to Keith and Sterrett the Carolina Gneiss is Precambrian in age and is unconformably overlain by the Blacksburg Schist and associated formations of Cambrian age. These Cambrian rocks also are said to overlie unconformably the upper Precambrian Battleground Schist. Kesler (1944, p. 761–774; 1955, p. 377–382) showed that the calcareous metasedimentary rocks in this area grade westward by change in bulk composition and metamorphism into the high-rank metamorphic rocks called Roan Gneiss and Carolina Gneiss by Keith and Sterrett. At many places no difference can be seen between the Blacksburg Schist and the Carolina Gneiss or between the Blacksburg Schist and the Battleground Schist. Unconformities cannot be seen, and in our interpretation we specifically abandon the unconformity placed by Keith and Sterrett between the units which they called Blacksburg Schist and Carolina Gneiss. We have, therefore, included in the sericite schist unit the low-rank metamorphic parts of the Blacksburg Schist of Keith and Sterrett and the filaments of higher grade rocks shown by them as Carolina Gneiss inside, or just to the east of, the Blacksburg Schist.

The sericite schist unit as shown south and southwest of Cherokee County consists predominantly of sericite schist and thin layers of graphite phyllite in Union County and northern Laurens County. Between Duncan Creek in Laurens County and the Little River in Abbeville County, the unit is composed of muscovite schist, manganiferous muscovite schist, kyanite muscovite schist, and sillimanite-muscovite schist. From the neighborhood of the Little River in Abbeville County to the Savannah River, the unit is dominantly sericite schist. Where the unit is kyanite or sillimanite muscovite schist, many filaments and pods of granite are present.

Manganese-rich beds were shown by Keith and Sterrett (1931, maps) in the upper part of the Battleground Schist in Cherokee and

York Counties. Similar manganiferous schists have been observed elsewhere in the sericite schist unit of the Kings Mountain belt and in rocks of the Inner Piedmont, Charlotte, and Carolina slate belts. Interbedding rather than infolding probably best explains the distribution of the manganiferous schists, but the fact that the schists occur in the upper units in both the Kings Mountain belt and Carolina slate belt is thought by us to be further evidence of the stratigraphic equivalence of these rocks.

Manganiferous mica schist occurs as large septa in the Yorkville Quartz Monzonite in Gaston County, N.C. (Espenshade and Potter, 1960, fig. 42). W. R. Griffitts (oral commun., 1960) found manganiferous mica schist in biotite schist of the Inner Piedmont belt exposed on the south-trending ridge at White Stone in Spartanburg County. Elsewhere in Spartanburg County, manganiferous mica schist occurs in gneiss, biotite schist, and hornblende schist 8 miles south of Glenn Springs (Sloan, 1908, p. 98); and manganiferous garnet schist is exposed on U.S. Route 221 between Enoree and Kilgore. Three layers of manganiferous muscovite schist crop out discontinuously for several miles in a narrow southwestward-plunging anticline in the Kings Mountain belt south of Laurens (Overstreet and Bell, 1960a, p. 28). Between the Kings Mountain belt and the slate belt, manganiferous rocks are exposed at places about 0.5 mile west of New Market and 3.5 miles south of Greenwood in Greenwood County (Sloan, 1908, p. 95). In the slate belt, manganiferous rocks are sporadically exposed from a place between Callison and the junction of Horsepen Creek and Cuffytown Creek in Greenwood County southwestward to the vicinity of McCormick (Sloan, 1908, p. 95). Manganiferous sericite phyllite and sericite-quartz schist of the slate belt crop out one mile northwest and between 1.5 and 2 miles west of McCormick in McCormick County, S.C. (Sloan, 1908, p. 96) and also in Lincoln, Wilkes, and Taliaferro Counties, Ga. (Beck, 1946, map).

MARBLE AND QUARTZITE

Thin discontinuous beds of marble and quartzite are found in the sericite schist unit of the Kings Mountain belt in Cherokee (Mills, 1826, p. 24) and Union Counties and in adjacent schists in the Inner Piedmont belt in Cherokee, Spartanburg, Laurens, and Greenwood Counties.

The marble in Cherokee and York Counties was named the Gaffney Marble by Keith and Sterrett (1931, maps). It was called Cambrian in age because of its low metamorphic grade and the structural position assigned to it. Direct evidence of age from fossils was not presented. Subsequent workers have also failed to find direct evidence of the age of the Gaffney Marble, and it has not been correlated by geologic mapping to rocks of known stratigraphic position.

The Gaffney Marble of Keith and Sterrett consists of fine- to medium-grained blue to white dolomitic marble that contains unevenly distributed amounts of muscovite, phlogopite, quartz, microcline, epidote, hornblende, sphene, clinozoisite, rutile, ilmenite, apatite, and chlorite (Kesler, 1944, p. 767–768). Many beds are pure enough to have been quarried as a source for lime, and the rock is now quarried for road metal. It forms three long narrow bands and one thick mass in Cherokee County. The mapped extent of Gaffney Marble ends in the complexly folded and thickened mass just south of Gaffney. No outcrops of marble are known southwest of Gaffney along the projected strike of the unit.

Northeast of Gaffney, layers of banded white to gray fine- to medium-grained marble occur in graphite mica schist at the Kings Mountain gold mine in Gaston County, N.C., about 2 miles south of the town of Kings Mountain (Keith and Sterrett, 1931, p. 3). White medium-grained marble in a layer 20 feet thick is known in the hornblende schist unit on the west side of Kings Creek in Cherokee County, S.C., about 6 miles east-northeast of Blacksburg (Keith and Sterrett, 1931, p. 3).

South of Gaffney, exposures of marble along the Kings Mountain belt are limited to two beds in a single outcrop 2 miles southwest of Cross Keys in Union County (Johnson, 1958). The beds 2 feet and 5 feet thick, are composed of white coarsely crystalline magnesium-rich dolomitic marble. They are separated by several feet of phyllite, and the lower bed is separated from underlying porphyroblastic biotite gneiss by a layer of diopside-actinolite calc-silicate rocks.

Marble crops out in the vicinity of the Musgrove Mill Monument, Laurens County, 4.5 miles southwest of and on strike with the marble at Cross Keys. It is interbedded with schists of the Inner Piedmont belt slightly west of a band of hornblende schist in the Kings Mountain belt.

Most other exposures of marble in the Piedmont of South Carolina are in western Laurens County, from Lick Creek to the Saluda River. These outcrops are confined to a band of hornblende gneiss of the Inner Piedmont belt. It seems appropriate, however, to discuss them here because we think that the same two sequences of sedimentary and volcanic rocks in the South Carolina Piedmont are exposed in this part of the Inner Piedmont and Kings Mountain belts (pl. 1). The marble in Laurens County and in Cherokee County may be derived from the same discontinuous calcareous sediments deposited during the youngest sedimentary and volcanic episode shown in table 4.

Descriptions of individual exposures of marble were given by Clarke (1957), Sloan (1908, p. 230–233), and Tuomey (1848, p. 117–118). These authors indicated that the beds of marble are high-rank metamorphic rocks and that they are associated with rocks of like metamorphic grade. Clarke stated that dolomitic marble exposed between the Reedy River and Walnut Creek is interbedded with muscovite quartzite and intruded by biotite granite and pegmatite. Reactions between the marble and granite produced contact zones rich in scapolite and actinolite. Sloan described marble exposed southwest of Ware Shoals as being slightly dolomitic and containing green pyroxene; it is interbedded with hornblende schist and biotite-muscovite schist. He also described beds of marble near the forks of North and South Rabon Creeks—possibly the deposits discussed by Tuomey (1848, p. 118)—where the marble is interlayered with hornblende gneiss and soapstone.

Marble exposed in the vicinity of Laurens occurs in two broad bands of hornblende gneiss in the Inner Piedmont. We infer that the bands of gneiss are stratigraphic equivalents and that they occur in the middle sequence of sedimentary and volcanic rocks. One of these bands extends from near Gaffney, in Cherokee County, southwest to the Enoree River; the other band is in Laurens and Abbeville Counties. The marble in these bands may be a correlative of the marble in the Kings Mountain belt near Gaffney, but more likely it is a separate, unrelated marble layer. The unconformity that underlies the marble and associated rocks in the upper sequence of sedimentary and pyroclastic rocks in the Gaffney area has not been found in the vicinity of Laurens.

The marble at Cross Keys, Union County, probably is a discontinuous layer in the upper sequence of the Kings Mountain belt shown in table 4, and it is a correlative of the Gaffney Marble. The marble beds in the hornblende gneiss near Laurens and the marble at Cross Keys cannot be correlated with certainty.

Amphibole, pyroxene, and other minerals are persistently formed in the marble and in the less calcareous sedimentary facies of the marble, exposed sporadically from Cherokee County to the Saluda River. The marble is locally associated with layers of hornblende gneiss. The more siliceous, tuffaceous, or clayey the original calcareous sediment was, the more silicate minerals that could form in it during metamorphism (Kesler, 1944, p. 764–768). Hence we conclude that the purest limestone in the depositional basin is now preserved as small lenses and discontinuous layers of marble; and siliceous, tuffaceous, or clayey facies of the limestone now appear as the associated hornblende gneiss. Present discontinuities in the distribution of the marble are inherited from discontinuities in the deposition of clean calcareous sediments. Doubtless some, and possibly much, of the noncalcareous components of the marbles and associated hornblende gneiss was pyroclastic in origin.

The principal beds of quartzite in the Kings Mountain belt are the white quartzite, chlorite-sericite quartzite, kyanite quartzite, sillimanite quartzite, and quartz conglomerate exposed in Cherokee and York Counties. They were named the Kings Mountain Quartzite and the Draytonville Conglomerate Member and called Cambrian in age by Keith and Sterrett (1931, p. 5). These authors used the same general regional relations to assign ages to the quartzites as they used for the marble. The many divergent views expressed since the work by Keith and Sterrett reflect the intricate problems posed by the sedimentation, stratigraphy, structure, and metamorphism in the Kings Mountain area (Smith and Newcome, 1951; Potter, 1954, p. 78–133; Espenshade and Potter, 1960, p. 76–79; Kesler, 1944, p. 762; 1955, p. 377–378). The principal conclusion on which there is agreement is that the quartzites are folded polymetamorphosed sediments (Espenshade and Potter, 1960, p. 84). Whether the folds are synclines or anticlines is vigorously debated. It seems to us that the largest fold in which the quartzites occur is a broad north-plunging anticline defined by the trend of the sericite schist and hornblende schist units of the Kings Mountain belt. The quartzite on both flanks of the anticline is in tightly compressed synclines.

The extensive discussion of the quartzites has tended to give the impression that they are large in volume and lithologically characteristic of the Kings Mountain belt. They are thin and discontinuous, however, and in this respect resemble the layers of marble. Like the marble, they tend by increments of clay and volcanic ash to lose their unique lithology and through metamorphism to merge into the surrounding mica schists and gneisses. In the vicinity of Crowders Mountain and the Pinnacle in Gaston County, N.C., the beds of quartzite are associated with schistose pyroclastic rocks (Potter, 1954, pl. 1). The sparseness of quartzite in the Kings Mountain belt and its local association with pyroclastic rocks resembles the distribution of quartzite in the Carolina slate belt. In South Carolina, outside of Cherokee and York Counties, quartzite is unknown in the Kings Mountain belt, although quartz-sericite schist and quartz-muscovite schist are very common. South of Laurens, quartz-kyanite-muscovite schist and sillimanite-muscovite schist occur locally in the Kings Mountain belt. However, the appearance of argillaceous quartz-rich rocks in the Laurens area where marble also occurs may have some stratigraphic and structural significance.

INTRUSIVE ROCKS

The intrusive rocks in the Kings Mountain belt in South Carolina were described by Keith and Sterrett (1931), Kesler (1944), and Espenshade and Potter (1960). Their descriptions show that in the Kings Mountain belt the mutual relations of the intrusive rocks and the relations between the intrusives and their wallrocks are strikingly similar to the relations in the Carolina slate belt.

OLIGOCLASE TONALITE

Two small bodies of oligoclase tonalite are exposed in the sericite schist unit of the Kings Mountain belt northwest of Clover in York County. The rock was mapped by Potter (Espenshade and Potter, 1960, p. 72–73) and described as coarse-grained light-gray massive to gneissic oligoclase tonalite or metatonalite. It contains angular inclusions of biotite schist that range in length from 1 inch to 10 feet, and in places it is intruded into brecciated zones in the wallrocks. The bodies of oligoclase tonalite were albitized and silicified, and plagioclase was locally replaced by epidote during late-stage alteration. Regional metamorphism produced a foliation in the rock and locally created staurolite, garnet, and kyanite (Espenshade and Potter, 1960, p. 73).

The oligoclase tonalite intrudes biotite schist, biotite gneiss, hornblende gneiss, and muscovite schist, which on the large geologic map (Overstreet and Bell, 1965) are called the sericite schist unit of the Kings Mountain belt. These schists and gneisses are the rocks called Bessemer Granite by Keith and Sterrett (1931, p. 4, map). The term Bessemer Granite, however, is not applicable in York and Cherokee Counties, S.C., and is not used on the geologic map. The relations between the rocks called Bessemer Granite by Keith and Sterrett and the sericite schist unit of the Kings Mountain belt have been described in the section on the sericite schist unit and are shown in table 4.

The oligoclase tonalite is intruded by dikes of metamorphosed quartz gabbro (Espenshade and Potter, 1960, p. 73) which are too small to show at the scale of the large geologic map. Both the oligoclase tonalite and the quartz gabbro are separated by an erosional unconformity from overlying schistose pyroclastic rocks (table 4, this report; Espenshade and Potter, 1960, p. 70).

YORKVILLE QUARTZ MONZONITE

The name Yorkville Quartz Monzonite is a revision by Espenshade and Potter (1960, p. 79–80) of the name Yorkville Granite, given by Keith and Sterrett (1931, p. 6) to several related varieties of rock exposed in York and Cherokee Counties. The most widespread variety of Yorkville Quartz Monzonite is gray to dark-gray porphyritic quartz monzonite. Along the west side of the main body of quartz monzonite in York County, coarse porphyritic gneissic biotite granodiorite is common. Fine- to medium-grained massive biotite granite and biotite-quartz monzonite and coarse porphyritic hornblende granodiorite are also present; and, according to Potter (1954, p. 135), subtle gradations exist from one rock to another.

The Yorkville Quartz Monzonite intrudes the sericite schist unit, the hornblende schist unit, and the oligoclase tonalite (Espenshade and Potter, 1960, pl. 7) in the Kings Mountain belt. It cuts across the belt and intrudes rocks of the Charlotte and Inner Piedmont belts. Contacts between the intrusive and its wallrocks are steeply dipping to vertical. Strong flow banding parallels the contacts. In many places the contact is a zone of interlayered fine-grained nonporphyritic quartz monzonite, schist, and felsic dikes. Intrusion of the quartz monzonite was accompanied by intense shearing adjacent to the contact and by warping of large folds (Espenshade and Potter, 1960, p. 83).

The Yorkville Quartz Monzonite is intruded by small fine-grained dikes having the same range in composition as the host, by granitic aplite dikes, by almandine-bearing pegmatite dikes (Espenshade and Potter, 1960, p. 79), and by mafic dikes of unknown composition. The felsic dikes are genetically related to the Yorkville Quartz Monzonite, but the relations of the mafic dikes are not known. Long septa of schist included within the Yorkville Quartz Monzonite show extensive contact metamorphism. Potter (1954, p. 149–157) recognized the septa as remnants of a metasedimentary and metavolcanic sequence and found among them sillimanite-muscovite schist, sillimanite quartzite, sillimanite conglomerate, corundum gneiss, garnetiferous sillimanite-biotite gneiss, manganiferous schist, spessartite rock, pyroxene granulite, hornblende gneiss, and cordierite hornfels.

The high-grade contact-metamorphic effects observed by Potter in the septa along the west side of the Yorkville Quartz Monzonite in the vicinity of Henry Knob are common elsewhere among rocks intruded by the Yorkville. Contact-metamorphic reactions around Yorkville Quartz Monzonite locally converted the rocks of the sericite schist and hornblende schist units of the Kings Mountain belt into high-rank schists and gneisses identical in appearance with the rocks found in the Charlotte and Inner Piedmont belts. This seems to be what has happened between the Broad River and the Pacolet River in Cherokee County, where the typical low-rank metamorphic rocks of the Kings Mountain belt are lacking and a core of Yorkville Quartz Monzonite occupies the center of a mass of Charlotte belt granitoid gneiss of high metamorphic rank. Beyond this possible contact aureole, the typical low-rank rocks of the Kings Mountain belt reappear. In the contact aureole surrounding the Yorkville Quartz Monzonite, the unconformities separating the three upper volcanic and sedimentary sequences cannot be recognized. What Keith and Sterrett (1931, maps) showed in this area as a complex structural termination of Blacksburg Schist, Roan Gneiss, and Battleground Schist against Carolina Gneiss and Roan Gneiss may be partly a change in metamorphic grade. In our interpretation of this area, the west limb of a broad north-plunging anticlinorium of Kings Mountain belt rocks was breached and metamorphically upgraded by the Yorkville Quartz Monzonite.

UNNAMED GRANITES

Granites for which names have not been proposed in the literature have been classified by us according to grain size and texture. (See p. 29). They appear throughout the Kings Mountain belt but are most common southwest of Laurens, where the sericite schist unit is highly metamorphosed. In Greenwood County one of these small plutons is coarse-grained granite and has a distinct fine-grained border phase.

MAFIC DIKES

Mafic dikes of various ages and relations have been observed in the Kings Mountain belt. They are discussed on pages 27 and 42.

INNER PIEDMONT BELT

The Inner Piedmont belt is between the Kings Mountain belt and the Brevard belt. It consists of plutonic schists and gneisses that are intruded by concordant and discordant igneous rocks of gabbroic to granitic character (Overstreet and Griffitts, 1955, p. 551–563). On the east the change between the rocks of the Inner Piedmont and rocks of the Kings Mountain belt is mainly a change in metamorphic grade rather than juxtaposition of formations of different ages. Locally, the change is complicated by faults, but the dominant characteristic of the change is a westward increase in grade of progressive regional metamorphism. The west side of the Inner Piedmont belt is marked by a zone of retrogressive cataclastic metamorphism as the Brevard belt is approached (Jonas, 1932, p. 238–239; Reed and others, 1961). The schists and gneisses of the Inner Piedmont are believed to lie on a basement of older rocks, but this relation has not been observed.

The prevailing high grade of metamorphism in the Inner Piedmont belt has resulted in an assemblage of gneisses and schists whose origin and subsequent geologic history are difficult to interpret and whose boundaries are difficult to define. The simple margins of the units shown on the geologic map (Overstreet and Bell, 1965) are an expression of lack of geologic detail rather than of freedom from geologic complexity.

The nearest approach to a systematic study of the metamorphic rocks across the Inner Piedmont belt in South Carolina is a map drawn by D. W. Caldwell and N. P. Cuppels (written commun., 1954) and a series of inferences based on study of detrital heavy minerals from small streams in the belt (Overstreet and Griffitts, 1955, p. 555–566).

We think that a stratigraphic sequence consisting of two sequences of volcanic and sedimentary rocks and two unconformities passes from the Kings Mountain belt to the Inner Piedmont belt through an increase in regional metamorphic grade in the direction of the Inner Piedmont. The transition from the lower-grade metamorphic rocks of the upper and middle episodes of sedimentation and volcanic activity in the Kings Mountain belt (table 4) to the high-grade metamorphic rocks of the intermediate and lower episodes of sedimentation and volcanic activity in the Inner Piedmont belt (table 2) takes place at a breach made in the Kings Mountain belt by the Yorkville Quartz Monzonite in southern Cherokee County. The metamorphic grade of the rocks changes southwestward from the albite-epidote amphibolite facies and lower metamorphic facies east of Gaffney to the kyanite-staurolite and sillimanite-alamandine subfacies of the amphibolite facies near Laurens. Several manganiferous beds are present in the uppermost stratigraphic unit, just as there are several distinct calcareous beds in the upper unit. Further evidence for the passage of the stratigraphic sequence across lithologic belts is indicated by the manganiferous mica schist of White Stone in Spartanburg County. It lies east of the hornblende gneiss in the Inner Piedmont belt, just as it lies east of hornblende gneiss in the Kings Mountain belt in Cherokee County.

The stratigraphy of the Inner Piedmont is unknown, and rocks of several stratigraphic positions may be present in the various map units. Indisputable relict bedding is scarce west of the Kings Mountain belt except in the vicinity of Walhalla, Oconee County, where marble, hornblende gneiss, and augen gneiss are interlayered, and near the Kings Mountain belt southwest of Cherokee County where some of the rocks exposed in the Kings Mountain belt can be traced into the Inner Piedmont belt. A certain broad symmetry of rock types in the Inner Piedmont belt, however, can be seen on the geologic map (Overstreet and Bell, 1965). Hornblende gneiss with local layers of marble is distributed along the southeastern and northwestern flanks of the belt. Between the bands of hornblende gneiss, the belt is composed of an array of biotite and sillimanite schists and gneisses that contain less muscovite in the core of the belt than toward the flanks. The core of the Inner Piedmont belt consists of migmatites and gneisses. Large discordant granite plutons are scarce, but many concordant granite bodies are present; pegmatite is remarkably abundant. The metamorphic grade of the rocks in the Inner Piedmont belt increases from the albite-epidote amphibolite facies and the lower temperature subfacies of the amphibolite facies along the flanks of the belt to the higher temperature subfacies of the amphibolite facies in the core.

From the similarity in the distribution of marble and hornblende gneiss on the two flanks of the belt, the two mafic zones might be assumed to define the limbs of a large and complex fold, possibly an anticline. If they do, then evidence for closure of the fold is lacking and, indeed, the broad western band of hornblende gneiss as a definable unit virtually disappears within the State. It is known, however, that the outlines of this band persist northeastward into North Carolina at least to the Catawba River as a zone of biotite-hornblende-oligoclase schist and gneiss. In North Carolina this schist and gneiss, like the hornblende gneiss in South Carolina, yields alluvial sediments to streams distinctly richer in hornblende, magnetite, and epidote than sediments in streams rising in the feldspar and sillimanite biotite schists and gneisses in the core of the Inner Piedmont belt (Overstreet and Griffitts, 1955, p. 555–565). No evidence for closure of the two mafic bands in North Carolina is given on the geologic map of the State (Stuckey and Conrad, 1958, map). Evidence for southwestward closure of the bands of hornblende gneiss does not appear on the geologic map of Georgia (Stose and Smith, 1939), but a southwestward change from hornblende gneiss to biotite-hornblende-oligoclase gneiss is indicated by the description of the geology of Hart County, Ga. (Grant, 1958, pl. 1). The refolded folds found by Grant in Hart County indicate that rock types exposed on the northwestern flank of the Inner Piedmont belt may reappear on the southeastern flank, but no certain stratigraphy can be traced.

The structure of the Inner Piedmont is as poorly known as is the stratigraphy. From the present information the most notable structural features in the Inner Piedmont are the late major cross folds. These folds have also been recognized in adjacent parts of North Carolina and Georgia. They affect the rocks in the Inner Piedmont and Kings Mountain belts, but they appear to be truncated by the Brevard belt. These folds are shown by regional changes in the trend of planar features. In northern Abbeville County the nearly easterly and coincident trends of the margin of the belt and of the foliation diverge. The trend of the margin of the belt is east, whereas the trend of the foliation is north across Anderson County into Greenville County. In the vicinity of Piedmont and White Horse, Greenville County, the trend of the foliation becomes northeast. This northeasterly trend continues into Cleveland County, N.C., where it is warped northward and northwestward. Across the Savannah River from Anderson County, a similar warping of northeasterly trends into strong northwest-trending arcs was found in the Inner Piedmont gneisses in Hart County, Ga. (Grant, 1958, pls. 1, 2). These divergent trends athwart the regional northeasterly grain appear to occur at 40- to 60-mile intervals.

METAMORPHOSED SEDIMENTARY AND VOLCANIC ROCKS

The metamorphosed sedimentary and volcanic rocks in the Inner Piedmont belt are discussed by map unit. The order in which they are presented does not necessarily reflect their stratigraphic position. Rocks of several stratigraphic positions may be included in a given map unit.

BIOTITE SCHIST

The biotite schist unit includes many varieties of fine- to coarse-grained scaly and strongly foliated biotitic rocks derived from pelitic sediments, felsic lavas, and pyroclastic rocks. The biotite schist is folded and contorted, and it encloses numerous pegmatite veins and segregations. Among the most common of the rocks in the unit is biotite-oligoclase schist. Its principal mineralogical variants are garnetiferous biotite-oligoclase schist, kyanite biotite-oligoclase schist, and sillimanite biotite-oligoclase schist. Muscovite-biotite schist—including varieties with staurolite, kyanite, sillimanite, and garnet—is rather scarce except near the Kings Mountain belt and in the far western part of the Inner Piedmont belt (C. Q. Brown and H. S. Johnson, Jr., written communs., 1959–60). Thin layers of biotite gneiss, graphite schist, quartzite, marble, calc-silicate rock, calcareous quartz-biotite gneiss, hornblende schist, and hornblende gneiss occur throughout the unit, and interlayering is common. Perhaps the most characteristic feature of the unit is the thinly layered habit of the schist, in which light-colored feldspar- and quartz-rich, layers alternate with dark biotite-rich layers. Owing to the thinness of the layers—at many places no more than 0.25 inch thick—and to the fine grain size of the material, the biotite schist unit, particularly where it is thoroughly weathered, resembles metamorphosed varieties of the laminated argillite in the Carolina slate belt and of the Battleground Schist of Keith and Sterrett (1931, p. 4–5), which on the large geologic map (Overstreet and Bell, 1965) is part of the sericite schist unit of the Kings Mountain belt.

QUARTZITE

The quartzite in the Inner Piedmont belt is gray, dark gray, or white. It ranges in composition from massive clean quartzite to mica-quartz schist and includes biotite quartzite, muscovite quartzite, garnet biotite quartzite, hornblende quartzite, diopside quartzite, kyanite quartzite, sillimanite quartzite, and graphite quartzite. A little quartzite is interbedded with marble and phyllite in Cherokee County at the State line just west of State Route 198. In Spartanburg County, some of the areas shown as quartzite are probably either quartz veins (Latimer and others, 1924, p. 423) or the quartz cores of pegmatite dikes. The quartzite at the head of Mountain Creek southwest of Anderson is interbedded with fine-grained schist. Considerable quartzite was shown by Lieber (1859, pl. 17) in Oconee County north and west of Walhalla in the area shown by us to be occupied by hornblende gneiss of the Inner Piedmont belt. This quartzite is associated with marble (Sloan, 1908, p. 227–230; McLendon and Latimer, 1908, p. 29–30). This area may contain the most extensive beds of quartzite in South Carolina west of the Kings Mountain belt, but adequate data from which to plot the distribution of the quartzite are lacking.

HORNBLENDE GNEISS

The hornblende gneiss unit in the Inner Piedmont belt consists of dark-gray, dark-green, or black fine- to coarse-grained gneissic, schistose, or massive hornblende rocks. They are metamorphosed igneous and sedimentary rocks. Rarely, those of igneous origin can be seen to grade into massive gabbro or diorite; and, very rarely, hornblende gneiss grades mineralogically into marble (Sloan, 1908, p. 430). With decrease in abundance of hornblende and increase in the proportion of biotite, the hornblende gneiss grades into biotite-hornblende-oligoclase gneiss and, ultimately, into biotite gneiss and schist. The hornblende gneiss is interlayered with the kinds of rocks that compose the biotite schist unit. Where hornblende schists and gneisses dominate over the biotite schists, the rocks are classed as the hornblende gneiss unit.

The principal varieties of rocks in the unit are garnet-bearing and garnet-free hornblende gneiss and schist, diopside-hornblende gneiss and schist, hornblende-diopside-biotite gneiss and schist, diopside-biotite gneiss and schist, diopside-labradorite gneiss, diopside-scapolite gneiss in which scapolite replaces labradorite, hornblende-biotite-oligoclase gneiss and schist, actinolite schist, and chlorite schist. The diopside-bearing rocks are the common calc-silicate rocks seen as thin layers and discontinuous lenticular masses throughout the Inner Piedmont belt. Also included in the hornblende gneiss unit are small masses of hornblende gabbro, olivine gabbro, pyroxenite, peridotite, and soapstone because data to separate them are inadequate. These mafic rocks, like the rocks called gabbro in the Charlotte belt, consist of an older group and a younger group. The older group is partly foliated and is intruded by gneissic granite, whereas the younger group consists of kidney-shaped bodies intruded only by lamprophyre and pegmatite that appear to be genetically related to the gabbro. Possibly syenite may also be associated with the younger gabbro, but none has been found in the Inner Piedmont. Bodies shown as hornblende gneiss of the Inner Piedmont belt but which we think are, or contain, gabbro occur in the following places: Near Iva, Anderson County, but in Abbeville County; at Pendleton in Anderson County; near the head of Martin Creek in Oconee County (Tuomey, 1848, map); at the end of the small body of hornblende gneiss exposed on the Chauga River northwest of Westminster; at a point 4–5 miles north of Walhalla (Sloan, 1908, p. 150–151); at a point 2 miles east of Gramling (Tuomey, 1848, map); at Delmar in Spartanburg County (Lieber, 1858b, pl. 14); at places 1.5 miles southeast of Eastatoe, 3 miles south of Rocky Bottom, 1.5 miles west of Six Mile Mountain, and in the area west of Central, Pickens County; and places near the mouth of Warrior Creek and just west of the confluence of North Rabon and South Rabon Creeks in Laurens County (Tuomey, 1848, map). Bodies of gabbro have been reported (Sloan, 1908, p. 151) in the Whiteside Granite at the extreme head of the North Fork Little River in Oconee County and in migmatite near the junction of Beaver Creek with the Rocky River in Anderson County.

Rocks of the hornblende gneiss unit are intruded by granitic rocks of various ages. In places where fragments of hornblende gneiss are included in the granitic rock, thick reaction rims of coarse flaky biotite have formed around the fragments of gneiss (Overstreet, Theobald, and Cuppels, 1953, p. 25).

MARBLE

Thin discontinuous layers of marble occur along the southeastern and northwestern flanks of the Inner Piedmont belt. Locally, the marble contains accessory amphibole, quartz, biotite, phlogopite, muscovite, or garnet (Conrad, 1960, p. 37–38).

Occurrences of marble in the southeastern part of the Inner Piedmont belt in South Carolina have already been described in the discussion of the Kings Mountain belt. In addition to these occurrences, two small beds of marble are known in the eastern part of the Inner Piedmont belt in Cherokee County.

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Keith and Sterrett (1931, p. 3) described a bed of marble that crops out in a stream a few hundred yards south of Thicketty. The bed is 3 feet thick, but only a zone 1 foot thick is pure marble. The rest of the marble contains coarse grains of biotite, quartz, and feldspar; and, with decrease in the abundance of the carbonate minerals, it grades into biotite schist. This outcrop is in an area where interlayered units of biotite schist and hornblende gneiss of the Inner Piedmont are cut by the Yorkville Quartz Monzonite. Therefore, these units and the marble may be part of the stratigraphic sequence of the Kings Mountain belt that was raised by contact metamorphism to the grade typical of rocks in the Inner Piedmont belt.

Clarke (1958) described an outcrop of marble on State Route 198 in Cherokee County very near the border with North Carolina. The marble is dark gray, fine grained, dolomitic, and intensely contorted and fractured. Overlying and in fault contact with the marble is quartzite and feldspar-rich gneiss. Clarke related the marble to that in the Kings Mountain belt and suggested that it is a detached remnant resulting from high-angle normal faulting of Middle Triassic age. Unrecognized faults of Triassic age must exist in the Piedmont; nevertheless, we think that the continuity of adjacent rock units precludes extensive Triassic faulting at this locality. The marble is probably an interbedded layer in a septum of schist in the Cherryville Quartz Monzonite. Intense deformation was localized along the septum when the Cherryville Quartz Monzonite was emplaced.

Marble is present in northwestern South Carolina in two bands in Oconee County (Overstreet and Bell, 1965). The easternmost of the two bands is discontinuously exposed on the ridges about 4 miles northwest of Walhalla in an area underlain by the hornblende gneiss unit. The westernmost of the two bands consists of discontinuous bodies of marble exposed in the valleys of Brasstown Creek and the Chauga River in an area underlain by the schists of the Brevard belt. Early descriptions failed to distinguish the considerable difference in the metamorphic grade and structural history of the two bands of marble. The two bands were correlated and included as part of the Brevard belt (Lieber, 1859, pl. 17; Keith, 1907, p. 4; McLendon and Latimer, 1908, p. 29–30; Sloan, 1908, p. 225–230). Later workers (Jonas, 1932, p. 239; King, 1955, p. 358) accepted the early correlation. Recent fieldwork by J. W. Clarke,[2] H. S. Johnson, Jr. (written commun., 1960), J. C. Reed, Jr. (written commun., 1960), and by us shows that the two bands of marble are separate, noncorrelative units.

[2] Clarke, J. W., 1958, The carbonate rocks of the Piedmont of South Carolina and a résumé of the regional geology: Manuscript report filed with the Division of Geology, South Carolina State Development Board, Columbia, S.C. Made available to us through courtesy of the author and H. S. Johnson, Jr., State Geologist.

The marble in the Inner Piedmont belt is an amphibolite-facies metamorphic rock, whereas the so-called marble in the Brevard belt is associated with rocks of the greenschist facies. The Brevard belt is not a stratigraphic feature; it is a fault zone that cuts across the hornblende gneiss unit and its interbedded marble of the Inner Piedmont belt.

The marble cropping out in the hornblende gneiss unit of the Inner Piedmont belt on the ridges about 4 miles northwest of Walhalla was correlated by Lieber (1859, pl. 17) with the marble at Brasstown Creek in the Brevard belt. McLendon and Latimer (1908, p. 29–30) inferred that the same lentils of marble in the Inner Piedmont belt of Oconee County were remnants of Brevard belt rocks from which the characteristic soft micaceous schist and phyllite were entirely removed by weathering. Sloan (1908, p. 430–431) described the marble and accompanying rocks in the Inner Piedmont belt under the name "Poor Mountain zone," which he stated comprises dark calcareous slate, marble, hornblende schist, chloritoid schist, and quartzite. He described the gradation of white marble in this zone into pyroxene-bearing rocks and the gradation of the pyroxene-bearing rocks into hornblende gneiss and schist (Sloan, 1908, p. 430). He correlated these rocks with the Brevard schist of Keith (1907, p. 4). The low metamorphic grade ascribed by Sloan to parts of the mafic schists and gneisses associated with the marble in the hornblende gneiss unit of the Inner Piedmont belt in Oconee County—and apparently used by him to substantiate the correlation with the Brevard belt—has not been observed by recent workers. J. W. Clarke (written commun., 1958) found that the marble near Walhalla is in the lowest subfacies of the amphibolite facies and that rocks of the greenschist facies, such as described by Sloan for the Poor Mountain belt, are not present. Similar findings were reported by H. S. Johnson, Jr. (written commun., 1960). The parts of the marble that we observed are not associated with low-grade metamorphic rocks but are interbedded with hornblende schist, hornblende gneiss, and migmatite.

The marble in the hornblende gneiss unit exposed northwest of Walhalla contains less MgO than do marbles in the Brevard belt, the Kings Mountain belt, or other parts of the Inner Piedmont belt in South Carolina (table 5). It contains only a trace of dolomite but has 5–50 percent quartz and phlogopite (H. S. Johnson, Jr., oral commun., 1960; Sloan, 1908, p. 225–226). It is white, whereas the marble in the Brevard belt is blue to gray and very dolomitic. The range in composition of the marbles in South Carolina may result from differences in the composition of the original sedimentary carbonate rock; or it may result from differences in metamorphic grade and degree of metamorphic differentiation. Without more detailed knowledge of the metamorphic changes that the rocks have undergone, it is impracticable to speculate on possible correlations that might be inferred from the composition of the marble. There is, however, considerable similarity between the average composition of marble in South Carolina (table 5) and the composition of many samples of marble and dolomite from the Piedmont and Blue Ridge of North Carolina (Conrad, 1960, p. 51–54).

TABLE 5.—*Average composition of marble in South Carolina*

[Analyses, in percent, from Sloan (1908, p. 256–261) and from J. W. Clarke (written commun., 1958) and averaged by W. C. Overstreet, 1960]

Number of analyses in average	Location	CaO	MgO	Al_2O_3	Fe_2O_3	SiO_2
18	Inner Piedmont belt, Oconee County	39.87	0.75	2.54	1.38	22.43
4	Inner Piedmont belt, Laurens and Greenwood Counties.	35.32	15.18	.39	1.52	4.37
1	Inner Piedmont belt, Cherokee County	27.49	15.82	.76	1.03	18.42
1	Kings Mountain belt, Union County	39.18	14.74	.12	.28	1.13
7	Kings Mountain belt, Cherokee County	40.05	8.30	.78	.28	10.31
3	Brevard belt, Oconee County	27.50	12.04	4.22	.33	18.36

The marble and hornblende gneiss of the Inner Piedmont belt near Walhalla were shown by King (1955, p. 358, map) and by K. H. Teague (H.S. Johnson, Jr., written commun., 1960) as a southwest-trending spur of the Brevard belt. That interpretation is derived from old descriptions that are inadequate in lithologic, metamorphic, and structural criteria for correlation. We think that the Brevard belt is a fault zone much younger than the marble and hornblende gneiss near Walhalla and that it cuts through these rocks. The marble in the Brevard belt in South Carolina apparently consists of tectonic slices (J. C. Reed, Jr., written commun., 1960) unrelated to the marble near Walhalla.

BIOTITE GNEISS AND MIGMATITE

The biotite gneiss and migmatite unit of the Inner Piedmont belt is light- to dark-gray fine- to medium-grained layered gneiss. It consists of biotite-oligoclase-quartz gneiss, garnet- biotite-oligoclase-quartz gneiss, garnet- biotite-oligoclase gneiss, biotite-sillimanite-oligoclase gneiss, biotite-sillimanite-almandine gneiss, and garnet-bearing gneisses of quartz monzonite to granodiorite composition. Throughout the unit are innumerable granitic layers, veins, and segregations of pegmatite, and metacrysts of plagioclase and potassium feldspar. Thin layers of schist, particularly biotite schist, sillimanite schist, and hornblende schist, are common. Discontinuous masses of calc-silicate rock, principally fine-grained diopside-labradorite gneiss often rich in sphene, calcite, and graphite, form small boudins or short, flat, lenticular layers. Quartzite layers in the unit are thin and commonly contain almandine, sillimanite, hornblende, or graphite.

The rocks of the unit are more massive and appear more granitic than do the rocks of the biotite schist unit of the Inner Piedmont belt. Rocks in the unit are principally of the sillimanite-almandine subfacies of the amphibolite facies in Cherokee, Spartanburg, Greenville, and Anderson Counties, and principally of the kyanite-staurolite subfacies in Oconee and Pickens Counties.

HENDERSON GNEISS

The Henderson Granite was named by Keith (1905, p. 4) from extensive exposures southeast of the Brevard belt in Henderson County, N.C.; the name was revised to Henderson Gneiss by Reed (1964). The Henderson is a nonlayered augen gneiss throughout the area southeast of the Brevard belt in North and South Carolina; and the term, as used by us in Oconee and Pickens Counties, S.C., is restricted to such rocks lying southeast of the Brevard belt as are traceable to the type locality. Rocks mapped by Keith (1905, map; 1907, map) as Henderson Granite northwest of the Brevard belt in Avery and Mitchell Counties, N.C., belong to a different unit (Eckelmann and Kulp, 1956; Reed and Bryant, 1960, p. B196).

The Henderson Gneiss in Oconee County is a light-gray to light-bluish-gray generally fine grained porphyritic and slightly gneissic rock (McLendon and Latimer, 1908, p. 20). Equigranular varieties of the rock grade into porphyritic varieties, and both kinds may be in a single outcrop. The Henderson is composed of orthoclase, plagioclase, quartz, and minor amounts of muscovite and biotite. Where the rock is both gneissic and porphyritic, the feldspar phenocrysts are 2 inches long and augen shaped. In the massive porphyritic Henderson Gneiss the phenocrysts rarely exceed 1 inch in length. Some outcrops show effects of strong shearing, and the coarse minerals of the original rock are thoroughly fractured and drawn out (Keith, 1907, p. 4).

Interbedding between the Henderson Gneiss and associated marble and hornblende gneiss was reported by H. S. Johnson, Jr. (written commun., 1960) in the area northwest of Walhalla in Oconee County. J. W. Clarke (written commun., 1958) originally identified the hornblende gneiss as basalt, and he thought the Henderson at this locality might be metamorphosed arkose.

The Henderson in Pickens County was reported by C. Q. Brown (written commun., 1960) to be characterized by a predominant augen structure. The augen phases range from light gray to dark gray and weather to a light color. The augen range greatly in size, even in the same hand specimen, but a common length is about 0.5 inch. Less common phases of the Henderson Gneiss in Pickens County are laminated contorted biotite gneiss and light-gray slightly schistose muscovite gneiss. The three phases are granitic in composition and contain abundant microcline. Brown observed that the quartz in the Henderson is granulated and that the mica is bent to conform to the shape of the augen. He further stated that the contact between the Henderson and the hornblende gneiss unit of the Inner Piedmont belt is one of the clearest contacts in the county and that it is concordant and gradational. Brown thought that the Henderson Gneiss may be a metamorphosed sedimentary rock.

Coarse porphyritic textures are uncommon among the plutonic granitic-textured rocks of the Inner Piedmont belt but do occur in the Charlotte belt and Carolina slate belt. In its coarse porphyritic texture, and in its immense linear extent, the Henderson Gneiss resembles the quartz-microcline gneiss unit of the Carolina slate belt.

The Henderson Gneiss in North Carolina is intruded by the Whiteside Granite of Keith southeast of the Brevard belt (Keith, 1907, map). We think, however, that the Whiteside Granite of Keith at the type locality northwest of the Brevard belt is not the same rock as the rock called Whiteside southeast of the Brevard belt. In South Carolina we refer to this rock as biotite granite gneiss and restrict the use of Keith's term Whiteside Granite to rocks northwest of the Brevard belt. The biotite granite gneiss in Oconee County appears to be locally intrusive into the Henderson Gneiss. It may be a more highly mobilized part of the Henderson.

BIOTITE GRANITE GNEISS

The term "biotite granite gneiss" is used by us for granitic rock underlying broad areas in the Inner Piedmont belt in Pickens, parts of Greenville, and Oconee Counties, following the usage of C. Q. Brown (H. S. Johnson, Jr., written commun., 1959) in Pickens County. The biotite granite gneiss is excellently exposed in a quarry 2.4 miles northeast of Liberty, Pickens County (Alfred and Schroeder, 1958, p. 2).

The biotite granite gneiss consists of orthoclase, oligoclase, quartz, biotite, and a little muscovite together with accessory magnetite, ilmenite, apatite, epidote, garnet, sphene, and local monazite (Keith, 1907, p. 4–5; Alfred and Schroeder, 1958, p. 2; J. B. Mertie, Jr., 1959, written commun.). It is commonly white to gray and is medium-grained. The rock is faintly to strongly gneissic, but it is locally threaded with dikes of massive fine- to medium-grained biotite-muscovite granite. Where the gneiss is layered, the layers are contorted into tight little folds which are usually recumbent and which are broken by small faults. Porphyritic texture occurs locally, and where the biotite granite gneiss is very porphyritic, it closely resembles the Henderson Granite (Keith, 1907, p. 5).

Most of the rocks adjacent to the biotite granite gneiss are schist and gneiss representing sedimentary and volcanic rocks metamorphosed to the staurolite-kyanite subfacies of the amphibolite facies. Along the southern contact of the biotite granite gneiss in Pickens County, some schists and gneisses of the sillimanite-almandine subfacies appear.

The biotite granite gneiss unit appears to us to include rocks of at least two different origins. The greater part of the unit is a sequence of sediments that has been intricately folded and metamorphosed to the kyanite-staurolite and sillimanite-almandine subfacies of the amphibolite facies and forms a gneiss of granitic composition. Locally, this gneiss was mobilized during metamorphism and intruded its wallrocks. Some time after the gneiss was formed, it was fractured and injected by magma from which dikes and other bodies of massive fine- to medium-grained biotite-muscovite granite crystallized. Possibly the massive granite is considerably younger than the biotite granite gneiss.

The biotite granite gneiss in northern Pickens County and northwestern Greenville County within the boundary of the Pisgah quadrangle was called Whiteside Granite by Keith (1907, map, p. 4–5). Keith also stated that the Whiteside Granite extends southwestward from the Pisgah quadrangle for considerable distances in South Carolina and Georgia.

The biotite granite gneiss unit in southwestern Oconee County is a northeastern extension of Lithonia-type biotite granite gneiss shown on the geologic map of Georgia (Stose and Smith, 1939) and discussed by Crickmay (1952, p. 42).

Neither the name Whiteside Granite nor the name Lithonia Granite seems to us to be applicable to this rock in these parts of South Carolina. The Whiteside Granite in its type locality northwest of the Brevard belt at Whiteside Mountain in Jackson County, N.C., is coarser, more contorted, richer in muscovite and in pegmatite dikes, and possibly richer in inclusions than is the rock mapped by Keith (1907, map) as Whiteside Granite southeast of the Brevard belt in Pickens and Greenville Counties (Reed and others, 1961). The Lithonia Granite was named by Crickmay (1952, p. 42) from exposures at Lithonia, DeKalb County, Ga.; however, as used on the geologic map of Georgia, the name was not restricted to a specific rock. According to Crickmay, all the strongly gneissic bodies of granite in Georgia were mapped as Lithonia type, but differences in composition and texture within the unit show that several distinct kinds of rock were lumped together. Thus, there is no certainty that the biotite granite gneiss in Oconee County is the same rock as that exposed at Lithonia, Ga. For the purposes of this report, the term "biotite granite gneiss" is appropriate.

INTRUSIVE ROCKS

The intrusive rocks in the Inner Piedmont belt include a few altered and deformed mafic dikes, two named granitic rocks, muscovite pegmatite dikes from which commercial mica has been obtained, and some unnamed bodies of granite. Very little has been done to classify the granitic rocks into mappable units. As they produce soil that resembles the soil formed on adjacent gneiss and schist, their boundaries cannot be identified on soil maps.

GABBRO AND SOAPSTONE

Unmetamorphosed and metamorphosed mafic and ultramafic rocks ranging in composition from gabbro to soapstone form small circular to irregularly shaped bodies and dikes in the Inner Piedmont belt. The unit called gabbro and soapstone on the geologic map (Overstreet and Bell, 1965) consists of hornblende gabbro, olivine gabbro, pyroxenite, peridotite, and soapstone. Some of these rocks have not been distinguished from the hornblende gneiss unit because of inadequate data. Only those bodies are shown that can be located on existing maps (Lieber, 1859, pl. 17; Keith and Sterrett, 1931, map), but many more similar bodies of mafic rock—particularly thin disrupted dikes of gabbro having boudinage structure—probably occur in the Inner Piedmont belt.

The older group of mafic and ultramafic rocks was intruded before emplacement of the Toluca Quartz Monzonite, and they are possibly related to metamorphosed quartz gabbro dikes that were observed by Potter (Espenshade and Potter, 1960, p. 70) to intrude the oligoclase tonalite in the Kings Mountain belt. The younger group of mafic intrusives rather closely followed the intrusion of the Cherryville Quartz Monzonite (described below).

Both groups of mafic and ultramafic intrusive rocks recognized in the Piedmont of South Carolina are included in the gabbro and soapstone unit. Most of the rocks in this unit, however, probably belong to the older group because they are described as soapstone (Lieber, 1859, pl. 17) or as soapstone associated with gabbro (Keith and Sterrett, 1931, map). Alteration of the mafic rocks to soapstone is common in the older group of intrusives but very uncommon in the younger group. Members of the younger group probably exist in the Inner Piedmont belt, but we cannot distinguish them.

TOLUCA QUARTZ MONZONITE

The Toluca Quartz Monzonite is composed of gray gneissic, lineated, rarely porphyritic biotite-quartz monzonite. The name was given by Griffitts and Overstreet (1952, p. 779) to the western concordant masses of quartz monzonite in the Gaffney quadrangle, North Carolina and South Carolina; these masses had previously been mapped together with eastern discordant bodies of quartz monzonite by Keith and Sterrett (1931, map) as Whiteside Granite. The name Toluca Quartz Monzonite was taken from the community of Toluca, Cleveland County, N.C., which is near the excellent exposures at the type locality in the little quarry locally known as Acre Rock 0.8 mile southwest of Toluca. In South Carolina, good exposures of the Toluca Quartz Monzonite occur along streams between Grassy Pond and the Broad River, Cherokee County.

The rock is somewhat varied in composition, but it consists principally of oligoclase, microcline, orthoclase, quartz, biotite, and accessory garnet, zircon, and monazite. It is strongly gneissic along contacts but becomes nearly massive a few hundred feet from the contacts. Bodies of Toluca Quartz Monzonite generally conform to the structure of the enclosing biotite schist, biotite gneiss, and migmatite and are sheetlike in habit. Hence, outcrops tend to be long and narrow. The bodies of Toluca Quartz Monzonite are as intricately folded as the schists that enclose them. Only rarely do contacts of the quartz monzonite break across the foliation of the wallrocks, and commonly the crosscutting Toluca is a late-stage garnet-muscovite-biotite quartz monzonite. Crosscutting and concordant biotite pegmatite dikes and sills related to the Toluca Quartz Monzonite are very common, but none has been shown on the large geologic map (Overstreet and Bell, 1965). Inclusions of schist and gneiss in the Toluca Quartz Monzonite generally have thick reaction rims or are converted to whispy biotite-rich layers (Overstreet, Theobald, and Cuppels, 1953, p. 21).

Strong linear features in the quartz monzonite coincide with oriented sillimanite needles in the wallrocks. From these relations we interpret that the Toluca Quartz Monzonite was emplaced before, or at about the same time as, the Inner Piedmont belt was affected by strong regional plutonic metamorphism. Much later the Toluca was affected by fracture deformation and shearing. Under these conditions the biotite in the quartz monzonite and its wallrocks was recrystallized.

The term Toluca Quartz Monzonite is used for bodies of rock in Cherokee and Spartanburg Counties that have the characteristic features of the rock at its type locality. Some of the small concordant bodies of granitic rock in the migmatite core of the Inner Piedmont belt in Greenville County may possess the same characteristics. In south-central Greenville County and in Anderson County, there is an appreciable increase in the abundance of biotite and a decrease in quartz in rocks that resemble the Toluca Quartz Monzonite in attitude and in abundance of accessory monazite. Rocks similar to the Toluca Quartz Monzonite of Cherokee and Spartanburg Counties do not appear in Hart County, Ga. (Grant, 1958, pl. 1), across the Savannah River from Anderson County. We interpret these differences in mineral composition and the absence of quartz monzonite in Hart County, Ga., as being caused by a progressive southwestward change in the composition of the rocks from gneissic biotite quartz monzonite to gneissic biotite granodiorite. We think that the term Toluca Quartz Monzonite should not be extended southwest of Spartanburg County without careful geologic mapping.

CHERRYVILLE QUARTZ MONZONITE

The Cherryville Quartz Monzonite is composed of massive to faintly gneissic, locally strongly lineated, muscovite-biotite quartz monzonite. Both fine- and coarse-grained phases are known. It is composed of oligoclase, microcline, quartz, biotite, and muscovite. Accessory minerals are unusually sparse. Only traces of zircon, ilmenite, apatite, and monazite are present; and garnet is absent. Excellent exposures of the rock are in roadcuts near the junction of Buffalo Creek and the Broad River, Cherokee County, S.C.

The Cherryville Quartz Monzonite in South Carolina is the eastern part of the formation called Whiteside Granite by Keith and Sterrett (1931, maps) in the Gaffney and Kings Mountain quadrangles and reclassified by Griffitts and Overstreet (1952, p. 786–787). The older, western part was called the Toluca Quartz Monzonite, as previously explained; the younger, eastern part was named the Cherryville Quartz Monzonite, after Cherryville, N.C.

The Cherryville Quartz Monzonite forms a concordant to discordant elongate pluton in Cherokee County. It intrudes both the biotite schist unit and hornblende gneiss unit of the Inner Piedmont belt where those units are in the staurolite-kyanite subfacies of the amphibolite facies. Large rotated blocks of the schists are included in the Cherryville Quartz Monzonite, and long unrotated septa of the schist protude into it (Overstreet and Griffitts, 1955, map; Keith and Sterrett, 1931, maps). Reaction in the inclusions has chiefly resulted in the formation of coarse-grained crosscutting muscovite.

MUSCOVITE PEGMATITE

White coarse-grained zoned muscovite-plagioclase-quartz-perthite pegmatite dikes, sills, and pod-shaped masses are common throughout the biotite schist unit of the Inner Piedmont belt. The muscovite pegmatite dikes have been intensively studied (Griffitts and Olson, 1953) because they are sources of sheet mica. Throughout the southeastern Piedmont the muscovite pegmatite dikes range in composition from quartz monzonite pegmatite to quartz diorite pegmatite; they nearly everywhere occur in highly foliated metamorphic rocks, particularly mica and hornblende schist and gneiss, that are rich in plagioclase (Jahns, Griffitts, and Heinrich, 1952, p. 8–12).

These pegmatites are uncommon in the biotite gneiss and migmatite unit and the hornblende gneiss unit in South Carolina. The muscovite pegmatite is rare in wide areas underlain by the Henderson gneiss and by the biotite granite gneiss, and it is not found in the low-rank metamorphic rocks of the Kings Mountain belt. No dikes of muscovite pegmatite have been found in the Brevard belt in South Carolina; but in North Carolina on State Route 9 at Laky Gap about 2 miles south of Black Mountain, Buncombe County, a blastomylonitic remnant of a body of muscovite pegmatite was found in the Brevard belt and shown to us by Bruce Bryant. The twisted books of muscovite were as much as 4 inches across and were completely replaced by sericite.

Until recently, no acceptable and widely applicable regional synthesis for the origin and distribution of the muscovite pegmatite dikes had been evolved. Past efforts to relate the muscovite pegmatite dikes to bodies of granite have not explained why commercial muscovite pegmatite dikes are restricted to zones of high-rank metasedimentary rocks and are absent from the largest areas of exposed granite in South Carolina. A more profound control on the distribution of the pegmatites than mere contiguity to granite seems likely.

Griffitts (1958, p. 83–97) examined the geologic conditions affecting pegmatite deposits in the Inner Piedmont belt in Cherokee and York Counties, S.C., and in Cleveland, Gaston, and Lincoln Counties, N.C. He found that swarms of pegmatite dikes are rarely associated with large bodies of granite but that they ordinarily occur in areas containing small bodies of granite. The location of the swarms of dikes that contain large muscovite crystals appeared to Griffitts to relate to geologic conditions that favored a proper cooling history for the pegmatite dikes. The proper cooling history was achieved where the pegmatite magma entered rocks in which the pressure-temperature conditions of the kyanite-staurolite subfacies of regional metamorphism were prevailing. Apparently very little commercial muscovite formed in pegmatites that crystallized in higher temperature environments than that of the kyanite-staurolite subfacies. Griffitts also postulated that some as yet undeciphered structural control aided in the localization of the swarms of muscovite pegmatite dikes.

To these observations and conclusions we think that some factor of lithologic control should be added. The swarms of muscovite pegmatite dikes are mainly in schistose rather than in gneissic or massive rocks. The processes by which the great areas of massive granitoid gneiss and granite were formed in the Charlotte belt were singularly unproductive of pegmatite dikes of any kind, and they completely failed to produce dikes containing sheet muscovite.

The locations of many large individual pegmatite dikes are well known and are shown on the geologic map (Overstreet and Bell, 1965), but many smaller dikes also exist. An immense number of gneissic pegmatite sills of quartz monzonite composition but lacking sheet muscovite are associated with the gneisses in the core of the Inner Piedmont belt. They are distinctly older than the sheet-mica pegmatites in the belt.

UNNAMED GRANITES

The unnamed granites in the Inner Piedmont belt have been classed as coarse-grained granite and as granite undivided. The areal extent of some of these bodies of granite is poorly known. Their composition appears to be varied, and both the coarse-grained and undivided granites become darker and more calcic from Spartanburg County to Anderson County. In Anderson County, gneissic granodiorite may be a common rock in these two units.

BREVARD BELT

The Brevard belt in South Carolina is a segment of a long, narrow band of rocks extending northeastward from Alabama at least to Surry County, N.C. (Reed and Bryant, 1960, p. B195). The belt extends uninterruptedly across Georgia and South Carolina. Although rarely more than 6 miles wide and commonly less than 3 miles wide, the Brevard belt is at least 375 miles long (King, 1955, p. 356). It is a major geologic feature in the southern Appalachians; but despite the frequency with which it is mentioned in the literature, it is not well known. In consequence, the Brevard belt and the pronounced topographic lineament which marks its course in the Carolinas have been variously interpreted as a tight synclinal downwarp of Paleozoic sediments into Precambrian metamorphic rocks (Keith, 1905, p. 5), as a syncline bounded by a fault on its southeastern side (Stose and Smith, 1939, map), as a sedimentary facies of Precambrian gneiss which has localized some faulting (Crickmay, 1952, p. 26), as a "dejective zone" having great structural depth and in which faulting may be significant (King, 1955, p. 350–351), as a zone of retrogressive rocks along an overthrust fault of regional magnitude (Jonas, 1932, p. 238–239; Stose and Stose, 1951), as a normal fault (White, 1950, p. 1314–1325), and as a zone of retrogressive rocks along an overthrust or strike-slip fault (Reed and Bryant, 1960, p. B197). We think that the Brevard belt is a zone of phyllonite and blastomylonite formed by cataclastic retrogressive metamorphism of plutonic gneisses of the Inner Piedmont and Blue Ridge belts where these belts meet along a great strike-slip fault (Reed and others, 1961).

METAMORPHIC ROCKS

PHYLLONITE, BLASTOMYLONITE, QUARTZITE, AND DOLOMITE

The rocks in the Brevard belt were collectively named the Brevard Schist by Keith (1905, p. 5) from exposures near Brevard in Transylvania County, N.C. They were not divided into formations by him. The Brevard Schist of Keith in South Carolina was described by McLendon and Latimer (1908, p. 28–29) and by Sloan (1908, p. 430–431) as dark-gray to nearly black graphite phyllite, "fish-scale" muscovite schist, muscovite-graphite schist, chlorite schist, muscovite-quartz schist, biotite schist, quartzite, and limestone. J. W. Clarke (written commun., 1958) noted that at many places in the Brevard belt in South Carolina the rocks are too fine grained to be called schists, although their metamorphic grade is predominantly the muscovite-chlorite subfacies of the greenschist facies (Turner, 1948, p. 96). The quartzite forms discontinuous layers; and the limestone, which is commonly blue and dolomitic, occurs as lentils in nearly black phyllite (J. W. Clarke, written commun., 1958).

The quartzite was originally described and mapped under the name itacolumite (Lieber, 1859, pl. 17), but the areas shown by Lieber as being underlain by this rock are now known to include a large amount of phyllonitic rock, some leached siliceous marble (H. S. Johnson, Jr., oral commun., 1960), and some flinty blastomylonite (Jonas, 1932, p. 239). The location and lithology of the lentils of quartzite mentioned by McLendon and Latimer (1908, p. 28–29) are not known well enough to be shown on the geologic map (Overstreet and Bell, 1965), but the lentils may be bodies of true quartzite whose size and discontinuity are similar to those of the bodies of dolomite.

The dolomite in the Brevard belt in South Carolina has variously been called limestone or marble and has been assigned by different authors to the Precambrian and Cambrian. It was first reported in 1826 in the valley of Brasstown Creek, Oconee County (Mills, 1826, p. 24). Lieber (1859, pl. 17) correlated limestone in that stream with the marble exposed in the Inner Piedmont belt a few miles west of Walhalla, Oconee County. Hammond (1883, map) showed limestone and marble in the Brevard, Inner Piedmont, and Kings Mountain belts as being correlative and Huronian in age. Keith (1907, p. 4) thought the Brevard Schist with its lentils of limestone rested unconformably on Precambrian rocks, and he called the schist and limestone Cambrian in the northeastern part of Oconee County. Sloan (1908, p. 430–431) and McLendon and Latimer (1908, p. 28–29) extended Keith's age assignment across Oconee County to the Georgia border. Jonas (1932, p. 238) thought the marble in the Brevard belt in the Carolinas was Precambrian in age. Teague and Furcron (1948) regarded the marble, quartzite, and schists of the Brevard belt in Habersham County, Ga., as being Cambrian or younger(?) in age. Crickmay (1952, p. 26) wrote that the structural relations of the magnesian marble in the Brevard belt in Georgia were obscure, but he inferred a Precambrian age for the rocks in the belt.

Jonas (1932, 238–239) was the first to propose that the phyllite and schist of the Brevard belt are not low-grade progressively metamorphosed sedimentary rocks distinctly younger than adjacent plutonic gneisses and schists. She interpreted the Brevard Schist of Keith to be retrogressive phyllonite and the itacolumite of Lieber to be mylonitized granite. The Brevard belt itself she regarded as the trace of the Martic overthrust fault on which Precambrian rocks of the Piedmont slid westward in late Paleozoic time. The faulting took place along the horizontal lower limb of a great fold overturned toward the northwest. Grinding and crushing of the Precambrian plutonic gneisses and schists in the fault zone reduced their metamorphic grade from at least the middle subfacies of the amphibolite facies through all gradations to the greenschist facies. Jonas also discovered that much of the quartzite in the Brevard belt was fine-grained ultramylonite. She (p. 238) related the limestone in the Brevard belt to an inferred sedimentary sequence in the metamorphic rocks of the overriding block and implied that the bodies of marble are tectonic slices in the fault zone; she did not, however, positively state the mechanism that led to the position of the marble units in the fault zone. Linear features and the dip of foliation in the Brevard belt were not described, although the fault zone was said (Jonas, p. 230–231) to have formed by extreme westward dislocation along the horizontal limb of a nappe.

In a later paper, Stose and Stose (1951, p. 1371) showed that the foliation in the Brevard belt strikes about N. 45° E. and dips 45°–60° SE. They stated that the belt truncates other Appalachian structures from North Carolina to Alabama and that old gneisses along the belt are mylonitized in a band at least 0.5 mile wide.

Rocks mapped by Keith (1905) as small infolded masses of Brevard Schist northwest of the main Brevard belt in the vicinity of Old Fort, McDowell County, N.C., were shown by Hamilton (1957) to be cataclastic gneisses containing minor amounts of phyllonite. Cataclastic foliation strikes northeastward and dips 15°–60° SE. A strong cataclastic lineation in the plane of the foliation strikes northeastward and plunges gently northeast or southwest. It was interpreted by Hamilton (p. 571) to have formed normal to the direction of tectonic transport. The strong cataclasis was accompanied by recrystallization mainly at the biotite-chlorite subfacies of the greenschist facies and by some recrystallization at both the muscovite-chlorite subfacies of the greenschist facies and at the albite-epidote amphibolite facies. Hamilton (p. 572) interpreted the geologic relations as showing that the rocks mapped by Keith as Brevard Schist in the Old Fort area are mostly polymetamorphic schists derived from plutonic rocks. He thought the retrogression was part of an episode of regional metamorphism in the Blue Ridge that closed with the formation of pegmatite dikes at Spruce Pine, N.C.

Strong cataclasis and horizontal lineation were observed by J. W. Clarke (written commun., 1958) in the rocks of the Brevard belt in South Carolina.

A zone of blastomylonite and porphyroclastic schist and gneiss was reported by Reed and Bryant (Reed and Bryant, 1960; Bryant and Reed, 1960, p. 5) to occupy the topographic lineament that is the northeastward extension of the Brevard belt in the Table Rock quadrangle, North Carolina.

The Brevard belt between the Table Rock quadrangle and Stephens County, Ga., appears at all places visited by us, including the type locality of the Brevard Schist at Brevard in Transylvania County, N.C., to consist of retrogressive metamorphic rocks of polymetamorphic character except for the dolomite (Reed and others, 1961). The dolomite does not appear to have as complex a metamorphic history as do the retrogressive metamorphic rocks with which it is associated (J. C. Reed, Jr., written commun., 1960). It is a sedimentary rock that has been progressively metamorphosed to the muscovite-chlorite subfacies of the greenschist facies. It appears to occur as tectonic slices in the other rocks. This dolomite may possibly be, or be equivalent to, the Shady Dolomite (Keith, 1903, p. 5) of Early Cambrian age exposed in western North Carolina and eastern Tennessee.

We have not seen the quartzite in the Brevard belt in South Carolina, but it may have a history similar to that of the dolomite and be incorporated in the cataclastic gneisses and phyllonites as tectonic slices. The name Brevard Schist, given to these rocks by Keith (1905, p. 5; 1907, p. 4), is not used on the large geologic map (Overstreet and Bell, 1965), because the rocks are not a unique sequence of sedimentary rocks; they are a tectonic feature. We follow King (1955, p. 356) in calling this tectonic feature the Brevard belt. To the rocks within the

Brevard belt we apply the lithologic terms "phyllonite," "blastomylonite," "quartzite," and "dolomite." Several ages of rocks are doubtless included within the Brevard belt, but the characteristic phyllonite and blastomylonite of the belt may be Permian in age and older than diabase dikes of Late Triassic(?) age.

HENDERSON GNEISS

The masses of Henderson Gneiss shown in the Brevard belt (Overstreet and Bell, 1965) are here interpreted as relicts of Henderson that are not as thoroughly cataclastically deformed as are adjacent phyllonite and blastomylonite. In this interpretation the Henderson is involved in the Brevard fault zone; but the rock is neither intruded into Brevard Schist, as postulated by Crickmay (1952, p. 26), nor is it a base on which the Brevard Schist was deposited, as interpreted by Keith (1907, map). Where the typical augen structure of the Henderson Gneiss is thoroughly destroyed, the identity of Henderson is lost, and the resulting rock is dark phyllonite and blastomylonite.

INTRUSIVE ROCKS

Igneous rocks intruded into the Brevard belt have not been observed in South Carolina, but southwest of Collettsville, Caldwell County, N.C., the retrogressive rocks of the Brevard fault zone are cut by unmetamorphosed diabase dikes of Late Triassic(?) age (Bruce Bryant and J. C. Reed, Jr., written commun., 1961). In Hall and Gwinnett Counties, Ga., both a fault marking the southeastern edge of the Brevard belt and the rocks in the belt itself are cut by unmetamorphosed diabase dikes of Late Triassic(?) age (Stose and Smith, 1939, map).

BLUE RIDGE BELT

The Blue Ridge belt is the small area in South Carolina west of the Brevard belt. It is composed of layered biotite schist and gneiss, hornblende schist and gneiss, granite, muscovite pegmatite, quartzite, and dolomite. The schist and gneiss may be part of the plutonic rocks of the Blue Ridge that underlie the nonhornblendic metasedimentary rocks of the Ocoee Series of Late Precambrian age in North Carolina and Georgia (King, 1955, p. 360). We agree with Keith (1907, map) that in the northern part of Oconee County, S.C., the schists and gneisses in the Blue Ridge belt are Precambrian in age. We think that they are the oldest rocks in South Carolina, and we know of no equivalent rocks exposed southeast of the Brevard fault.

METAMORPHOSED SEDIMENTARY AND VOLCANIC ROCKS

BIOTITE SCHIST AND BIOTITE GNEISS

The schists of the biotite schist and biotite gneiss unit of the Blue Ridge belt consist of gray fine- to coarse-grained scaly biotite-oligoclase schist, garnet-biotite schist, muscovite-kyanite schist, and muscovite-staurolite schist. The gneisses of the unit are strongly layered, folded, and contorted biotite-oligoclase gneiss, garnet-biotite gneiss, and granitic gneiss. They appear to be part of an immensely thick sequence of metasedimentary rocks that is interlayered with mafic metavolcanic rocks, of which the thickest layers are shown as the hornblende schist and hornblende gneiss unit on the geologic map (Overstreet and Bell, 1965).

The biotite schist and biotite gneiss of the Blue Ridge belt in South Carolina was called mica slate of ancient Precambrian age by Hammond (1883, map). Hammond correlated the schist and gneiss with metamorphic rocks in the Inner Piedmont and Charlotte belts. Stose and Smith (1939, map) called the same rock in the parts of Georgia adjacent to Oconee County, S.C., biotite gneiss and schist of Precambrian age. Keith called these rocks the Carolina Gneiss. In the Southeastern States the name Carolina Gneiss has been applied to such diverse sequences of biotitic rocks that it no longer has correlative value; it has become synonymous with a particular lithology regardless of age or origin and has been abandoned (Brobst, 1962, p. A7). For these reasons, we use the term "biotite schist and biotite gneiss" for such rocks shown on the geologic map. The unit is thought by us to comprise the oldest rocks in South Carolina.

HORNBLENDE SCHIST AND HORNBLENDE GNEISS

The unit called hornblende schist and hornblende gneiss in the Blue Ridge belt of South Carolina consists of dark-green, gray, or black fine- to medium-grained locally garnetiferous hornblende schist, hornblende gneiss, biotite-hornblende gneiss, and biotite-hornblende-oligoclase schist. Locally, the unit includes massive medium- to coarse-grained diorite and gabbro and, rarely, small bodies of pyroxenite and serpentine. The hornblende schists and gneisses are interlayered with the biotite schists and gneisses, and much of the interlayering appears to be relict bedding. Crosscutting relations exist between the massive mafic rocks—such as the diorite, gabbro, pyroxenite, and serpentine—and the layered schists. Perhaps the interlayered part of the hornblende-rich rocks was laid down as lava flows and ash falls when the original sedimentary sequence was deposited. The crosscutting rocks were intruded as dikes, possibly during several periods of igneous activity, after the sediments had been deposited.

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The hornblende schist and hornblende gneiss were called hornblende slate by Hammond (1883, map), who said that they were older than the rocks we call the biotite schist and biotite gneiss unit. In northern Oconee County the hornblende schist and hornblende gneiss were called Roan Gneiss by Keith (1907, map). Keith considered the Roan Gneiss to be Precambrian in age and to be largely intrusive into the biotite schist and biotite gneiss. The interlayered parts of the hornblende schist and hornblende gneiss appear to us to be contemporaneous with the biotite-rich rocks. Inasmuch as the name Roan Gneiss has come to refer to lithology predominately rich in hornblende and not to a particular formation and has been abandoned (Brobst, 1962, p. A7), we use the terms "hornblende schist" and "hornblende gneiss" in the Blue Ridge belt.

TALLULAH FALLS QUARTZITE OF TEAGUE AND FURCRON (1948)

The Tallulah Falls Quartzite, as defined by Galpin (1915, p. 119), is a medium-grained quartzite exposed at Tallulah Falls on the border of Rabun and Habersham Counties, Ga. According to Galpin the quartzite contains muscovite, biotite, garnet, and varied amounts of feldspar. It apparently grades conformably into adjacent schist and gneiss, and it was thought by Galpin to be Precambrian or Early Cambrian in age. The quartzite crops out in a northeast-trending elongate dome, the easternmost tip of which projects across the Chattooga River (Teague and Furcron, 1948) into the Blue Ridge belt in Oconee County. In Oconee County we found the thin layer of "fish-scale" muscovite schist shown by Teague and Furcron to overlie the Tallulah Falls Quartzite in Georgia, as well as garnet and biotite gneisses immediately below the muscovite schist. The upper part of the Tallulah Falls Quartzite is reported to be rich in biotite and to be interlayered with garnet-biotite gneiss (Crickmay, 1952, p. 9). There is no doubt that this rock and the muscovite schist occur in South Carolina, but we have not seen true quartzite with these rocks in Oconee County. The small area of Tallulah Falls Quartzite shown on the geologic map of Georgia (Stose and Smith, 1939) does not reach the Chattooga River, and it may not occur in South Carolina.

The structure in which the quartzite occurs and the rock units said by Teague and Furcron (1948, map) to be characteristic of the upper part of the Tallulah Falls Quartzite in Georgia extend into South Carolina even though the true quartzite may not. Therefore, on the large geologic map (Overstreet and Bell, 1965) we have called the rocks underlying this small part of Oconee County the Tallulah Falls Quartzite of Teague and Furcron (1948) to show that the gneissic rocks in the upper part of the Tallulah Falls Quartzite, as modified by Teague and Furcron from Galpin's (1915, p. 119) original description, enter South Carolina.

The age of the quartzite was given as Precambrian or Early Cambrian by Galpin (1915, p. 119), as Precambrian by Stose and Smith (1939), as Precambrian (?) or younger by Teague and Furcron (1948, map), and as Precambrian by Crickmay (1952, p. 9–11). We think that the Tallulah Falls Quartzite of Teague and Furcron (1948) is Precambrian in age because it is reported to grade into underlying and overlying rocks that are Precambrian in age and because it is metamorphosed to the same staurolite-kyanite subfacies of the amphibolite facies as the associated rocks.

DOLOMITE

Dolomite associated with phyllonite occurs a short distance northwest of the Brevard belt in the Blue Ridge belt. It is probably a tectonic slice similar to the lenticles of dolomite found in the Brevard fault zone.

INTRUSIVE ROCKS

MAFIC DIKES

Metamorphosed mafic dikes have not been described from the small part of the Blue Ridge belt in South Carolina, but they have been observed as close as 4.5 miles northeast of the intersection of the State line with the eastern edge of the mass of Whiteside Granite in northern Oconee County (Keith, 1907, map, p. 3–4). The dikes are composed mainly of serpentinized peridotite, pyroxenite, and dunite. They are older than the Whiteside Granite.

A corundum-bearing peridotite dike, possibly equivalent to the young group of gabbro and pyroxenite dikes in the Piedmont, intrudes the Whiteside Granite in Oconee County (Sloan, 1908, p. 151).

WHITESIDE GRANITE

The Whiteside Granite is a biotite-muscovite granite consisting of orthoclase, plagioclase, quartz, biotite, muscovite, and accessory magnetite, ilmenite, garnet, epidote, pyrite, zircon, and monazite. Three mineralogic phases of Whiteside Granite are known in addition to the biotite-muscovite granite: muscovite granite, biotite granite, and, rarely, mica-free granite. The Whiteside is white to light gray and fine to medium grained; typically it is faintly to strongly gneissic, but some of it is massive. It is locally porphyritic, and at many places, pegmatitic (Olson, 1952, p. 3). Narrow dikes and sills of coarse-grained pegmatite cut the granite. The Whiteside Granite has generally concordant contacts and occurs in the form of large sills that dip gently southeastward (Olson, 1952, p. 3).

The wallrocks adjacent to the bodies of Whiteside Granite are commonly migmatites impregnated with granitic and pegmatitic material (Olson, 1952, p. 5). Both these mixed rocks and the Whiteside are cut by thin massive unfoliated granite dikes made up of quartz, microcline, plagioclase, biotite, and muscovite.

The Whiteside Granite was named by Keith (1907, p. 4) after Whiteside Mountain in Jackson County, N.C. The name was first used in his description of the Pisgah quadrangle, North Carolina and South Carolina, but the type locality is in the Cowee quadrangle, North Carolina. Keith used the name Whiteside Granite for rocks in both the Blue Ridge and the Inner Piedmont belts in the Pisgah quadrangle. However, the Whiteside Granite of Keith southeast of the Brevard belt is lithologically different from the Whiteside northwest of the Brevard belt. Because of these differences, the name Whiteside Granite is here restricted to the rocks described by Keith (1907) at the type locality in Jackson County, N.C., and to similar rocks in other localities northwest of the Brevard belt.

MUSCOVITE-PERTHITE PEGMATITE

Four dikes of pegmatite, which we have called muscovite-perthite pegmatite on the geologic map (Overstreet and Bell, 1965), are known in the Blue Ridge belt in Oconee County. They have been prospected for sheet muscovite (Griffitts and Olson, 1953, p. 322; H. S. Johnson, Jr., written commun., 1960). The four dikes define a narrow northeast-trending zone which projects into the Cashiers pegmatite district of Transylvania and Jackson Counties, N.C. (Olson, 1952, pl. 1). The northeasternmost pegmatite dike in the Blue Ridge belt in Oconee County is about 12 miles southwest of the southwesternmost dike in the Cashiers district.

The muscovite-perthite pegmatite dikes in the Blue Ridge belt in Oconee County consist of perthite, plagioclase, quartz, muscovite, and accessory garnet. The muscovite has a conspicuous "A" structure (Griffitts and Olson, 1953, p. 322) which is not present in the mica of the Cashiers district in North Carolina (Olson, 1952, p. 5). In other details, however, these pegmatite dikes appear to resemble those at Cashiers. For this reason, and also because these dikes are separated from the muscovite pegmatite dikes of the Inner Piedmont belt, we think that the muscovite-perthite pegmatite dikes in the Blue Ridge belt are different, particularly in age, from the pegmatite dikes in the Inner Piedmont.

ROCKS OF MESOZOIC AND YOUNGER AGE

UNDIFFERENTIATED SEDIMENTARY ROCKS OF TRIASSIC AGE

Three small areas underlain by conglomerate, sandstone, and shale of late Triassic age were reported by Buie and Robinson (1949, p. 5–6) north of Pageland in Chesterfield County. These areas represent the southwestern extension of the Wadesboro basin in North Carolina (Reinemund, 1955, p. 11–12). Sloan (1908, p. 433) also described Triassic rocks in this region. These sedimentary rocks dip 15°–20° SE. and are much fractured and intruded by diabase dikes. Sloan reported (1908, p. 433) that the dikes produced some contact metamorphism in parts of the red sandstone; and Tuomey (1848, p. 68) stated that sandstone adjacent to the dikes is altered to compact, hard, black rock and to material resembling kiln-fired brick.

Sandstone of Triassic age at the Brewer and Edgeworth gold and copper mine 2 miles southwest of Hornsboro, Chesterfield County, was reported by Lieber (1858a, p. 52) to be cut by a quartz vein of a "peculiar stratiform character." The vein, which is said to contain pyrite and auriferous chalcopyrite, cuts upward through argillite of the Carolina slate belt into the unconformably overlaying sandstone of Triassic age. Apparently the sandstone is only a few tens of feet thick (Lieber, 1858a, pl. 4, fig. 4) and probably occupies considerably less area than indicated by Lieber (pl. 6), for it is not shown in a map by Hammond (1883) nor is it reflected in the soils of Chesterfield County. The sandstone is, however, exactly where an extension of the sedimentary rocks in the Wadesboro basin might occur (Stuckey and Conrad, 1958, map). Other thin veneers of this sandstone may be present in the vicinity of Hornsboro, but the data are inadequate to show their distribution in the large geologic map (Overstreet and Bell, 1965).

The warped attitude both of the quartz vein in the sandstone and of other quartz veins in the underlying argillite was reported by Lieber to have been caused by the intrusion nearby of a large diabase dike of Triassic age. Thus, the auriferous quartz vein is apparently younger than the sandstone and older than the diabase dike. This may be the only gold vein reported in rocks of Triassic age in South Carolina, and its relations to the sandstone and diabase confine the probable time of emplacement to the Late Triassic. Pardee and Park (1948, p. 20) and Reinemund (1955, p. 123) stated that gold is not present in the Triassic rocks of the Carolinas.

DIABASE DIKES

Dikes of unaltered to slightly altered fine-grained diabase intrude all the rocks in South Carolina except the crystalline schists and gneisses of the Blue Ridge belt and the sedimentary rocks and alluvium of the Coastal Plain. The rock is typically a dark olivine diabase (Keith and Sterrett, 1931, p. 7; Ridgeway, 1960, p. 25; J. F. McCauley, oral commun., 1960) consisting of augite, labradorite, olivine, and magnetite. McCauley noted as much as 20 percent olivine in some diabase from Newberry and Kershaw Counties. Weathering causes a yellowish-brown or reddish-brown crust to form on joint surfaces of the dikes, and prolonged weathering converts the rock to an ocherous saprolite containing spherical residual boulders.

The dikes range in width from a few feet to at least 100 feet, and they range in length from a few thousand feet to possibly 25 miles. The longest dikes actually may be an en echelon series of short intrusive bodies, but their continuity is not known in detail. Most of the dikes strike between north and northwest and dip nearly vertically. A few dikes strike about east, and a very few dikes dip only 30°–60°. Where the diabase dikes intersect massive plutonic rocks, the dikes have few or no apophyses; but where they cut argillite of the Carolina slate belt, which seems to have fractured readily as the dikes were intruded, small apophyses are not uncommon (Sloan, 1908, p. 36). The diabase dikes intrude sandstone of Late Triassic age and are unconformably overlain by the Tuscalloosa Formation of Late Cretaceous age in South Carolina. They could be as old as Late Triassic or as young as Early Cretaceous. Closer evidence for their age is not available in South Carolina. They could be as old as Late Triassic or as young as Early Creconsidered to be Late Triassic(?).

UNDIFFERENTIATED SEDIMENTARY ROCKS OF THE COASTAL PLAIN

The largely unconsolidated sedimentary rocks of the Coastal Plain are shown as one unit on plate 1 and the large geologic map (Overstreet and Bell, 1965) to define the easternmost exposures of the crystalline rocks of the Piedmont. Except for Aiken County, where the rocks were mapped by Lang (1940, pl. 2), the distribution of the Coastal Plain sedimentary rocks was taken from soil maps.

Along the southeastern edge of the Piedmont, veneers of sediment only a few feet thick lie on the crystalline rocks. Wherever the sediment was reported to be thin and the underlying crystalline rocks was described in the discussion of the soil maps, the crystalline rock is shown on the large geologic map (Overstreet and Bell, 1965) instead of sediment. The main sedimentary rocks are the Tuscaloosa Formation of Late Cretaceous age and the McBean Formation and Barnwell Sand of Eocene age; in the valleys of the Savannah, Congaree, Wateree, and Pee Dee Rivers and in eastern Chesterfield County and most of Marlboro County, these units are overlain by formation of

Pleistocene and Recent age (Cooke, 1936, pls. 1, 2; Siple, 1946, p. 29–33). Some outliers shown as Coastal Plain sedimentary rocks within the area of crystalline rocks may be river gravels of Pliocene or Pleistocene age.

ALLUVIUM

Included under alluvium are flood-plain deposits, terrace deposits, and some colluvium. The flood-plain deposits are bedded poorly sorted unconsolidated stream-laid sediments which are strikingly similar over most of the mapped area. They rest on unweathered crystalline rocks, saprolitic crystalline rocks, or unconsolidated sediments of the Coastal Plain. In the area of crystalline rocks, 60–85 percent of the stream sediments is underlain by saprolite. Typically, the flood-plain deposits form a sequence having gravel at the base and silt at the top (P. K. Theobald, Jr., written commun., 1954):

Silt, sandy, red to brown.
Silt, clayey, buff, brown, or gray.
Sand, gray, buff, brown, coarse- to fine-grained.
Clay, gray, dense; has scattered quartz pebbles and lenses of coarse sand and carbonized wood; locally grades to muck or peat.
Gravel, quartz-pebble; has sandy clay matrix.

Commonly, the sequence is incomplete both along and across a flood plain, and it is not unusual for all units except one to be absent. The red to brown sandy silt is the most widespread and thickest unit. The total thickness of alluvium rarely exceeds 40 feet. In most flood plains shown on the map, the sediments are 10–30 feet thick.

The exposed flood-plain sediments are of Recent age, except isolated remnants of muck of late Pleistocene age in the headwaters of some valleys. The Recent alluvium can be divided into a late Recent (modern) sequence of red to brown sandy silt that has accumulated since agriculture was introduced into the region and an older Recent (pre-modern) sequence of buff and gray sediments in part underlying the modern sediments. The reddish-brown color of the modern sediments, as contrasted to the buff and gray colors of the pre-modern sediments, is a criterion, though not an infallible one, for separating modern and pre-modern sediments. Hard ferruginous concretions appear to be associated only with the pre-modern sediments (Happ, Rittenhouse, and Dobson, 1940, p. 65). Many contemporary artifacts are buried in the modern sediments.

The age of muck and carbonaceous debris in the alluvium and colluvium has been studied by carbon-14 measurements and by palynological and paleobotanical methods. Some of the deposits are of Recent age, and others are of Pleistocene age.

A sample of wood from muck of Recent age was collected by A. M. White of the U.S. Geological Survey from an exposure on North

Muddy Creek, 5.2 miles east of Marion and 1.3 miles south of Nebo, McDowell County, N.C. This sample (W7) was found through carbon-14 analysis by H. E. Suess (written commun., 1953) of the U.S. Geological Survey to be 2,370±200 years old. Using a different analytical method, J. L. Kulp of the Lamont Geological Observatory (written commun., 1955) determined an age of 2,680±200 years for another piece of the same log (sample L–167A).

Isolated remnants of muck and peat of Pleistocene age were described by Cain (1944, p. 19–20) in Spartanburg County and by Sloan (1908, p. 363–364) in Laurens County. The organic deposits are exposed in modern erosion gullies at the heads of streams and near the tops of divides. The muck and peat attain a maximum thickness of 16 feet, but they ordinarily occur as beds 1–3 feet thick. The muck is overlain by 5–20 feet of clayey unstratified to poorly bedded colluvium. Abundant spores and plant megafossils indicate a possible late Pleistocene age for these sediments (Cain, 1944, p. 19–20). Wood collected by N. P. Cuppels from a peat deposit exposed in a tributary to Buck Creek at Green Hill farm, 13 miles north of Spartanburg, was dated through carbon-14 analysis (sample W–308) by Meyer Rubin (written commun., 1955) U.S. Geological Survey and was found to be more than 34,000 years old.

Terrace deposits of older alluvium are very scarce except along large streams. Silty terrace deposits of probable Quaternary age are shown on the soil maps as alluvium 5–40 feet above the top of the present flood plains. Large silt-covered terraces of Quaternary and possibly older age are found on Coastal Plain sediments where trunk streams emerge from the Piedmont. Terrace gravels of possible Pliocene age (Heron and Johnson, 1958) occur about 130 feet above the present flood plains of the Saluda River in Lexington County. Patches of gravelly loam on the slopes leading to the present flood plain of the Wateree River in Fairfield County may be similar old terrace deposits.

Colluvial sediments, consisting mainly of mass-wasting deposits modified by sheet wash, are best exposed in gullies and in the headwater reaches of small streams. They unconformably overlie saprolite and unweathered rock. At their lower edge they are truncated by, spread out on, or interfinger with flood-plain sediments. Over most of the Piedmont the base of colluvial deposits formed by sheet wash is marked by thin discontinuous layers of angular pieces of quartz with which are mixed a few water-worn quartz pebbles and sparse blocks of unweathered bedrock. In the Carolina slate belt and in the Blue Ridge belt, the abundance of the rock fragments exceeds the abundance of pieces of quartz. The intermixed water-worn quartz pebbles are apparently derived from small isolated old fluvial deposits occurring at higher elevations. The angular rock fragments and quartz, together with the sand, silt, and clay of the matrix, are derived from local bedrock. Overlying the pebble layers is poorly sorted clayey sand which may be poorly and discontinuously bedded. The colluvial sediments lens out uphill or merge imperceptibly with residual deposits on the divides. The colluvial sediments appear to range widely in age: some are being formed at the present time, and some are Pleistocene in age or older.

INFERRED GEOLOGIC AGES

CONCEPTS UNRELATED TO AGES OF MINERALS

METAMORPHOSED SEDIMENTARY ROCKS

The geologic age of the metamorphosed sedimentary rocks in the South Carolina Piedmont has not yet been established from paleontologic evidence or established stratigraphy. The age of the rocks in the Blue Ridge belt in South Carolina is, perhaps, more certain, because the rocks are closer to known sequences of stratified rocks of late Precambrian and Paleozoic age. Inasmuch as the Piedmont is separated from the Blue Ridge by the great Brevard fault zone, the problem of assigning geologic ages to the crystalline rocks in the Piedmont is essentially independent of the problem of assigning ages in the Blue Ridge.

Efforts to find fossils, discern a stratigraphic succession, and assign ages to the rocks in the Piedmont have rightly been focussed on the low-grade metamorphic rocks of the Carolina slate belt. As early as 1844, Tuomey described the rocks in the slate belt in South Carolina as unfossiliferous and as late Precambrian (highest primary of Tuomey, 1844, p. 13, 19) in age.

Fossillike structures in rocks of the slate belt near Troy, Montgomery, County, N.C., were described in 1856 by Emmons (1856, p. 60–64). Some of the fossillike structures were interpreted by him to be siliceous corals, of which he distinguished and named two—*Palaeotrochis major* and *Palaeotrochis minor* (p. 62). Several structures found in the same rocks were interpreted to be obscure bryozoa and fucoids (p. 63). Because of the sedimentary aspect of the slates and the presence of so-called fossils, Emmons placed the slate-belt rocks below the Silurian and in the oldest part of the Paleozoic era, which he called the Taconic system (p. 41–68).

Two series were distinguished in the rocks of the slate belt by Emmons (1856, p. 41–68), but he cautioned that the division was obscure, a remark that has lost none of its pertinence in a hundred years. According to Emmons, the lower series was characterized by sericite (called talcose) slate, sandstone, and limestone. The upper series comprised green clay slate, chloritic sandstone, and brecciated conglomerate. Emmons (p. 51) correlated the lower series in the Carolina slate belt with the sericite schist and limestone in the Kings Mountain belt in Lincoln County, N.C. In this stratigraphic scheme the rocks in the Carolina slate belt and Kings Mountain belt were thought to be Cambrian in age or younger, but not as young as Silurian, and the rocks in the Kings Mountain belt were assigned the same age as the older rocks in the slate belt. They rested on Precambrian basement (primary series of Emmons).

The remarkable stratigraphic sequence inferred by Emmons actually appears to be a division of the slate belt rocks into a predominantly mafic sequence and a predominantly felsic sequence. We now think that both mafic and felsic rocks appear in a given age sequence and that a sequence of rocks of one age contains rock types similar to those of another age. However, Emmons' views on the Carolina slate belt were largely lost in the disputes regarding his Taconic system and in the discrediting of the organic origin of *Palaeotrochis*.

Specimens of *Palaeotrochis* were examined in 1868 by Marsh, who reported that they showed no microscopic features of corals (Marsh, 1868, p. 218). He concluded that they were concretions, as did Kerr in 1875 (p. 132). Some of the *Palaeotrochis* forms depicted by Emmons were identified by Nitze and Hanna in 1896 (p. 38–39) as spherulites common in quartz porphyry at the Moratock gold mine in Montgomery County, N.C. A few years late, Diller (1899, p. 62–66) showed that the so-called fossils were spherulites in metamorphosed volcanic rocks. Since Diller's paper was published, no fossils have been described from the slate belt or from more metamorphosed rocks of the Carolina Piedmont. In Virginia, however, undisputed fossils of Paleozoic age have been taken from slates whose appearance and position are similar to those of slates in the Carolina slate belt (Darton, 1892; Watson and Powell, 1911; Jonas and Watkins, 1932, p. 25–26).

A stratigraphic position older than Silurian for the rocks of the Carolina slate belt was accepted by Kerr (1875, p. 10), but he stated that the rocks were unfossiliferous and placed them in his Huronian system of late Precambrian age. He stated that the rocks of the slate belt rest unconformably on gneisses of Laurentian age (Kerr, 1875, p. 131–139).

A stratigraphic sequence adopted by Hammond (1883, map) for the crystalline rocks in South Carolina is very similar to the one proposed in 1875 for North Carolina by Kerr. Quartzite, phyllite, argillite, and limestone in the slate belt, Kings Mountain belt, and Brevard belt were correlated and assigned to the Huronian in South Carolina. Mica and hornblende schists were called Upper Laurentian in age throughout the crystalline area of South Carolina. Gneiss and granite were called Lower Laurentian in age by Hammond. He placed the Huronian above the Upper Laurentian and assigned the Huronian, Upper Laurentian, and Lower Laurentian to the Archean. Older than the Archean in Hammond's stratigraphic succession in South Carolina was the Azoic era, in which he placed an "Igneous system" to which he assigned steatite, trap, and porphyries.

Late Precambrian age for the rocks in the Carolina slate belt in North and South Carolina was accepted by Williams (1894, p. 3–4), Nitze and Hanna (1896, p. 44), Sloan (1908, p. 411), Arthur Keith in 1908 (Laney, 1910, p. 74), Pogue (1910, p. 95), Laney (1910, p. 73–74), Stuckey (1928, p. 25), and Jonas (1932, fig. 1). This position for the slate belt was coupled with the interpretation that the more metamorphosed rocks in the Piedmont were older Precambrian.

Late Precambrian and early Paleozoic(?) age for the rocks in the Carolina slate belt was proposed by Laney in 1917 (p. 56) and followed by Stuckey and Conrad in 1958 (p. 27), on the geologic map of North Carolina, and by Stromquist and Conley in 1959 (p. 4). Admission of an early Paleozoic(?) age for the low-rank metamorphic rocks in the slate belt is accompanied on the geologic map of North Carolina by a query of the antiquity of some of the high-rank metamorphic rocks in the Piedmont, and their age is given as Precambrian(?).

Paleozoic(?) age is attributed to the rocks in the Carolina slate belt by King (1951, p. 136; 1955, p. 353–354, map), who reasoned that the inner part of the Piedmont in the Carolinas may include much metamorphic rock of Paleozoic age.

The Cambrian age assigned by Keith and Sterrett (1931, p. 5–6) to conglomerate, quartzite, schist, and marble in the Kings Mountain belt and by Keith (1905, map) to the rocks in the Brevard belt in South Carolina was the youngest age given to metasedimentary rocks of pre-Mesozoic age in the Carolinas.

INTRUSIVE ROCKS

Ideas about the ages of the intrusive rocks in the Piedmont of the Carolinas were gradually modified from Hammond's view (1883, map) of a primitive "Igneous system" of great antiquity to the concept of Keith (1923, pl. 4) that the principal bodies of granite, occupying large parts of the Piedmont in South Carolina, were post-Carboniferous in age. Keith thought of the Piedmont as consisting of lower Precambrian sedimentary rocks intruded by gabbro, pyroxenite, diorite, and granite also of Precambrian age and much metamorphosed in Precambrian time. These rocks were subsequently intruded by massive post-Carboniferous granite batholiths. The emplacement of these great bodies of rock was accompanied by widespread metamorphism of the earlier rocks (Keith, 1923, p. 315; Hamilton, 1957, p. 571).

Despite tectonic and stratigraphic interpretations that differed profoundly from Keith's, Jonas (1932, fig. 1) also attributed a Precambrian age to the bulk of the metasedimentary rocks and to some of the plutonic intrusive rocks in the Carolinas. She considered the massive granites to be late Paleozoic in age.

Similar ideas regarding the ages of the intrusive rocks in Georgia were expressed by Crickmay (1952, p. 40–41), who stated that the older granitic rocks are associated with a Precambrian period of metamorphism and that emplacement of the upper Paleozoic granites followed a late period of metamorphism.

The possibility that the intrusive rocks in the Piedmont of the Carolinas were emplaced during several orogenic episodes in Paleozoic time was proposed by King (1951, p. 119–144; 1955) from considerations of tectonic evolution of the Appalachians. Fieldwork in small areas of the Carolina Piedmont supports this concept (Griffitts and Overstreet, 1952; Kesler, 1944; 1955, p. 374–387; Overstreet and Griffitts, 1955; and Bell and Overstreet, 1959).

CONCEPTS RELATED TO AGES OF MINERALS

Progress during the half century since the discovery of radioactivity has made it possible to determine the ages of many minerals by analysis of radioactive elements and their radiogenic daughter products. Thus it is possible to date an event in the history of the rock in which the mineral is found.

The age of a mineral in an unmetamorphosed igneous rock ideally is the age of crystallization of the mineral from a magma. However, in subsequent metamorphic events, part or all the radiogenic daughter isotopes might diffuse from such a mineral (Tilton and others, 1959, p. 172–173), and the determined age would be younger than the age of original crystallization. If the mineral lost all daughter products during the metamorphism, the measured age would ideally indicate the date of the metamorphic event. Partial loss of the daughter products would be indicated by a mineral having an age between that of the time of original crystallization and that of the time of metamorphism.

The age of a mineral in a metamorphic rock is modified by the degree to which the mineral has responded to the metamorphism. For minerals formed or recrystallized by metamorphism, the age ideally is the age of metamorphism. For detrital or igneous grains that did not recrystallize but from which earlier radiogenic daughter products diffused completely, the age ideally is the age of metamorphism. Incomplete diffusion of earlier former daughter products from a detrital grain would result in an apparent age older than the metamorphism but younger than the presedimentary age of the detrital grain.

The age of a mineral is thus not necessarily the age of the magmatic or metamorphic crystallization of the rock in which it occurs. It may be the age of an event or the resultant of several events in the history of the mineral. Efforts are ordinarily made to determine for the same rock the ages of several minerals having different degrees of metamorphic susceptibility and to interpret the age pattern against the known susceptibility of the minerals. Obviously, the petrology and geologic history of the rock must be well known before one can understand the meanings of the apparent ages of the minerals in the rock (Grunenfelder and Silver, 1958).

The minerals most frequently analyzed for age determinations in crystalline rocks are uraninite, zircon, biotite, muscovite, and microcline. Age determinations have less often been made on monazite, gummite, xenotime, thorite, thorianite, coffinite, sphene, apatite, allanite, fergusonite, samarskite, glauconite, lepidolite, magnetite, and others.

The methods now used most frequently to determine the ages of minerals depend upon radiogenic production of lead by the decay of uranium and thorium, the radiogenic production of strontium-87 from rubidium-87, and argon produced by the decay of potassium. A less commonly used method depends on the production of helium from the decay of the main radioactive elements. The relative abundances of lead, uranium, and thorium are measured in minerals like uraninite, zircon, and monazite by chemical analyses for the elements; by isotopic analyses to determine the ratios of U^{238}/Pb^{208}, U^{235}/Pb^{207}, Pb^{207}/Pb^{206}, and Th^{232}/Pb^{208}; and by spectrochemical analysis of lead together with measurement of alpha activity (Larsen, Keevil, and Harrison, 1949, p. 27–28; Rose and Stern, 1960). Isotopic determinations of Rb^{87}/Sr^{87} and of K^{40}/Ar^{40} are used to measure the age of such minerals as biotite, muscovite, and microcline (Wasserburg and Hayden, 1955; Wetherill, Aldrich, and Davis, 1955; Carr and Kulp, 1957; Davis and Aldrich, 1953; Aldrich, Wetherill, and Davis, 1956; and Aldrich, and others, 1956). The amount of helium in magnetite was measured by Hurley (1949, p. 79–80) to determine the age of the magnetite.

The extensive literature on the procedures and the assumptions in the methods and on the interpretation of the results was reviewed by Aldrich and Wetherill (1958) and by Goldich and others (1961, p.

8–35). The reader is referred to these reports for evaluations of the methods.

World-wide determinations of ages of minerals from rocks whose geologic position was reasonably well known were assembled by Holmes (1947) into two geologic time scales of which one, called the B scale, became widely used. The Holmes' B scale, as modified by Marble (1950, p. 1–18), was used in the U.S. Geological Survey for several years following 1954, during which time geologists became increasingly aware that it seemed to allow too short a span of time in the Paleozoic Era. By the end of 1959 the increase in geochronologic data led Holmes to present a revised time scale (Holmes, 1959, p. 204). In 1960, Faul (1960) showed the need for a lengthened time scale but concluded that the data at hand were too meager and too inconsistent to permit construction of a new scale.

The time scales for the Paleozoic era constitute the only reference by which the ages of minerals in the crystalline rocks in South Carolina can be related to geologic time. The ages of the minerals are the sole now available way to date the geologic events that have affected the rocks in the Piedmont. The relative ages of the rocks, however, have been deduced from the inferred stratigraphic sequence discussed above. Since 1952 we have sought the probable ages of the rocks in the Piedmont of the Carolinas by having ages of zircon and monazite determined in the laboratories of the U.S. Geological Survey. Table 6 shows the geologic time scales to which the results of this work have been referred. In prior reports (Overstreet and Griffitts, 1955, p. 566; Overstreet and others, 1961) we have referred the ages of the minerals from rocks in the Carolina Piedmont to the Holmes-Marble time scale. The longer time in the Paleozoic Era given by the revised Holmes scale (1959) seems to be in better agreement with field observations. In this report and on the geologic map (Overstreet and Bell, 1965), therefore, we have used the Holmes scale as a reference frame.

The ages of many minerals from the Carolinas and Georgia have been determined by the commonly used techniques and reported in the literature. In the following text we have used these ages, together with ages determined for us, and show how they appear to relate to the geologic history that we have interpreted for the crystalline rocks of South Carolina. We are not able and have not tried to reconcile analytical procedures used by the different authors. The ages reported fall into major groups which correspond to the major geologic episodes that we have interpreted from the field relations of the rocks. The ages of the older episodes are less certainly known than the ages of the younger episodes, however, because more time has elapsed during which the minerals have been altered and the apparent ages affected.

TABLE 6.—*Geologic time scales to which ages of minerals from the Carolinas have been related*

[Modified from Holmes (1959)]

Era	Period or system	Millions of years ago (approximate)	
		Holmes-Marble time scale of 1950 [1]	Revised time scale, Holmes (1959)
Mesozoic	Cretaceous	60–130	70±02–135±5
	Jurassic	130–155	135± 5–180±5
	Triassic	155–185	180± 5–225±5
Paleozoic	Permian	185–210	225± 5–270±5
	Pennsylvanian	210–235	270± 5–350±10
	Mississippian	235–265	
	Devonian	265–320	350±10–400±10
	Silurian	320–360	400±10–440±10
	Ordovician	360–440	440±10–500±15
	Cambrian	440–520	500±15–600±20
Proterozoic	Precambrian	520–2100+	

[1] Marble (1950, p. 1–18).

PREVIOUS WORK

A large amount of work has been done toward determining the ages of minerals in the Carolinas and relating the ages to geologic events. An important synthesis of the data on ages of minerals from the Appalachian region of the Eastern United States was presented by Rodgers (1952). He critically reviewed the analyses of radioactive minerals made before 1952 and reestimated the ages of these minerals according to new constants (Rodgers, 1952, p. 411–412). From this study, a pattern of four age groups emerged. The pattern was interpreted by Rodgers (p. 424–425) as showing four orogenic episodes in the Appalachian region that culminated 800 my (million years), 600 my, 350 my, and 260 my ago. Those culminating 800 and 600 my ago were represented by minerals from rocks exposed in Precambrian uplifts at the western edge of the crystalline part of the Appalachian system and were interpreted by Rodgers as being Precambrian in age. The episode culminating 350 my ago affected the same area in the Carolinas as did the Precambrian orogenies, but it was assumed to be Ordovician in age. Events of the orogenic episode culminating 260 my ago was not recognized from mineral dating in the Carolinas.

The oldest ages of zircon and microcline found in the core of the Appalachians from New York to North Carolina were shown by Davis and others (1958, p. 178) to be about 1,000–1,100 my; zircon crystals from the Cranberry Gneiss near Spruce Pine, N.C., had Pb^{207}/Pb^{206} ages as great as 1,270 my. Magnetite from the Cranberry mines in Avery County, N.C., interestingly enough, as early as 1948 had been dated by the helium method as 1,260 my old (Hurley, 1949, p. 82). Davis and others (1958, p. 179) also showed that the biotite in the

Cranberry Gneiss at Spruce Pine, N.C., was about 370 my old and appeared to date a late metamorphic event.

A chronology of major metamorphic events in the southern Appalachians was proposed in 1959 by Long, Kulp, and Eckelmann as the result of many new K^{40}/Ar^{40} and Rb^{87}/Sr^{87} ages for micas from crystalline rocks in North and South Carolina, Tennessee, and Georgia. The earliest plutonic metamorphic episode that they recognized in the Blue Ridge is the initial metamorphism of the Cranberry Gneiss in North Carolina and Tennessee at 900–1,100 my. They correlated this episode with the period of plutonic metamorphism in the Grenville Province of the eastern Canadian shield. A major orogenic episode in the southeast that is thought to have culminated at about 350 my largely obscured the earlier episode by causing partial to complete recrystallization of the micas. According to Long, Kulp, and Eckelmann (1959), the closing phases of this orogeny were marked by intrusion of pegmatite dikes in the Spruce Pine, Franklin-Sylva, and Bryson City districts, North Carolina, and by introduction of granite in the Piedmont of North Carolina and Virginia. An episode of plutonism dating from 230–310 my was recognized in the Piedmont of South Carolina and Georgia. Evidence was found for a regional metamorphic event between the episode at 900–1,100 my and the orogeny closing at 350 my. Its effects were largely lost in the event at 350 my.

This synthesis of geologic events in the Carolinas prior to Triassic time agrees closely with the succession of sedimentary sequences and intrusive episodes that we have deduced from field evidence in South Carolina. Four plutonic metamorphic episodes were recognized by Long, Kulp, and Eckelmann (1959) as having occurred in the Carolinas: (1) at 1,100–900 my, (2) sometime after 900 my but before 350 my, (3) at 350 my, and (4) at 310–230 my. These episodes seem to us to be regional metamorphic episodes that followed successively the deposition of sediments represented by the basement and the lower, middle, and upper sequences of sedimentary rocks. Possibly, the major event ascribed to 350 my by Long, Kulp, and Eckelmann was somewhat older than this, and the apparent ages have been reduced by metamorphic effects of the youngest episode. In the Piedmont and perhaps in the Blue Ridge, the youngest episode was more profound than was recognized by Long, Kulp, and Eckelmann.

PRESENT INVESTIGATION

The lead-alpha method of determining ages of minerals (Larsen, Keevil, and Harrison, 1949, p. 27–28) was being explored in the laboratories of the U.S. Geological Survey in the 1950's while we were doing fieldwork in the Carolinas. At an early stage of the laboratory investigation, we collected minerals from two quartz monzonite units whose field relations showed that they differed in age but whose absolute ages were not known. Preliminary results of the analyses (David Gottfried and H. W. Jaffe, written commun., 1954) disclosed that zircon and monazite from the older body of quartz monzonite were about 400 my old and, from the younger body, about 285 my old (Overstreet and Griffitts, 1955, p. 566). Over the ensuing 8 years to 1961, lead-alpha age determinations were made on 40 samples of zircon and 13 samples of monazite through the interest and cooperation of H. W. Jaffe and T. W. Stern (Jaffe, and others, 1959, p. 115–118; Gottfried, Jaffe, and Senftle, 1959, p. 21; Overstreet, and others, 1961). Results of the 53 analyses are shown in table 7, and the sample localities are given on plate 4.

TABLE 7.—*Lead-alpha age determinations on zircon and monazite from North and South Carolina*

Calculated age: E, alpha-activity measurements by H. W. Jaffe and David Gottfried, and spectrographic analyses for lead by C. L. Waring; L, alpha-activity measurements by T. W. Stern, and spectrographic analyses for lead by H. J. Rose, Jr., T. W. Stern, H. W. Worthing, Charles Annell, and Harold Westley. Th/U ratio in zircon from X-ray fluorescence analyses by F. J. Flanagan is 1.0 for samples 59–OT–100, 59–OT–101, 59–OT–102, 59–OT–110, and 59–OT–111 (M 1.5). Assumed 1.0 for other samples. Th/U ratio in monazite is assumed to be 25 except in the uranium-rich monazite in sample 53–BE–3 which has Th/U of 2.5 from analysis by Irving May.

Sample locality on plate 4	Field No.[1]	Rock type and locality	Mineral	Alpha per mg per hr	Average lead content from duplicate determinations (ppm)	Calculated age (millions of years)[2]
1	USNM 105674.	Large zircon crystals from zircon-rich vermiculite pegmatite 4 miles east of Tigerville, Greenville County, S.C.	Zircon	269	28	255±30 L
	60–OT–1001	Large zircon crystals from vermiculite quarry, Tigerville, Greenville County, S.C.	do	430	47	270±30 L
	60–OT–1002	do	do	443	46.5	260±30 L
2	USNM 80114.	Large zircon crystals from zircon-rich syenite pegmatite, Jones mine near Zirconia, Henderson County, N.C.	do	439	51	280±30 L
	60–OT–1000	do	do	756	95	300±45 L
3	53–BE–3	Cherryville Quartz Monzonite, Muddy Creek, Cleveland County, N.C.	Monazite	11,197	[3] 1,250	260 E
4	54–OT–225	Yorkville Quartz Monzonite, 1.7 miles south-southeast of Henry Knob, York County, S.C.	Zircon	533	[3] 58	260 E
5	59–OT–101	Coarse-grained, massive, porphyritic biotite granite 0.5 mile west of Lowrys, Chester County, S.C.	do	306	32	255±30 L
6	59–OT–100	Fine-grained, massive, biotite granite at Leeds Lookout Tower, Chester County, S.C.	do	145	28	460±50 L
7	59–OT–102	Massive biotite granite 5.5 miles S. 20° W. of Winnsboro, Fairfield County, S.C.	do	477	53	270±30 L
8	59–OT–107	Fine-grained massive granite 0.9 mile southwest of Blackjack, Fairfield County, S.C.	do	346	37	260±30 L
9	59–OT–110	Coarse-grained, massive, porphyritic biotite granite, 1.1 miles north of White Oak Creek, Kershaw County, S.C.	do	170	17	245±30 L

See footnotes at end of table.

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TABLE 7.—*Lead-alpha age determinations on zircon and monazite from North and South Carolina*—Continued

Sample locality on plate 4	Field No.[1]	Rock type and locality	Mineral	Alpha per mg per hr	Average lead content from duplicate determinations (ppm)	Calculated age (millions of years)[2]
10	47-MT-73	Toluca Quartz Monzonite 0.8 mile northwest of Toluca, Cleveland County, N.C.	Monazite	6,666	[3] 1,020	320 E
11	49-OT-14	Toluca Quartz Monzonite, Acre Rock Quarry, Cleveland County, N.C.	Zircon	450	[3] 83	440 E
	49-OT-16	Pegmatite related to Toluca Quartz Monzonite, Acre Rock Quarry, Cleveland County, N.C.	do	456	[3] 81	425 E
	49-OT-16b	do	do	452	[3] 82	435 E
	49-OT-16	do	Monazite	5,685	[3] 1,050	380 E
	53-OT-14	do	do	5,464	[3] 1,000	375 E
	53-OT-14	do	Zircon	652	124	455 E
12	49-OT-22	Late-phase Toluca Quartz Monzonite, Hollis Quarry, Rutherford County, N.C.	Monazite	7,068	1,290	375 E
13	54-OT-221	Late-phase Toluca Quartz Monzonite, 3.2 miles south of Dysartville, McDowell County, N.C.	Zircon	247	[3] 32	300 E
14	50-Y-328	Biotite-hornblende-oligoclase gneiss, 2.6 miles south-southeast of Hollis, Rutherford County, N.C.	do	231	[3] 34	355 E
	50-Y-328	do	Monazite	4,583	[3] 890	400 E
15	48-OT-81A	Biotite schist, 2 miles northeast of Lawndale, Cleveland County, N.C.	Zircon	257	[3] 45	420 E
	48-OT-81A	do	Monazite	5,298	[3] 1,000	390 E
	48-OT-81	do	Zircon	233	[3] 38	395 E
16	50-Y-538	Biotite schist, 2.4 miles south of Hopewell, Rutherford County, N.C.	Monazite	4,660	[3] 910	395 E
17	50-OT-441	Biotite schist, 1 mile northeast of Boiling Springs, Cleveland County, N.C.	do	4,573	[3] 920	415 E
18	54-OT-207	Henderson Gneiss, 1.4 miles east of Chimney Rock, Rutherford County, N.C.	Zircon	166	24.5	355 E
19	55-NC-5	Biotitic Whiteside Granite, Highlands, Macon County, N.C.	Monazite	4,321	768	370 E
20	55-NC-4	Biotitic Whiteside Granite, 5 miles west of Highlands, Macon County, N.C.	do	3,909	785	415 E
	55-NC-3	Muscovitic Whiteside Granite, 5 miles west of Highlands, Macon County, N.C.	do	3,600	765	440 E
	55-NC-3	do	Zircon	241	73	710 E
21	55-NC-2	Biotite schist, 6.3 miles east of Franklin, Macon County, N.C.	do	129	34	620 E
	55-NC-2	do	do	218	54	590 E
22	55-NC-7	Biotitic Whiteside Granite, 3.75 miles west of Cashiers, Jackson County, N.C.	Monazite	4,794	830	360 E
	55-NC-7	do	Zircon	924	270	670 E
23	IPE	Medium-grained biotite granite, Isenhour Quarry, Cabarrus County, N.C.	do	377	68	445±50 L
	IPF	do	do	458	68	360±40 L
	IPG	do	do	433	78	430±50 L
	IPH	do	do	398	49	300±35 L
	HB-39-59	Syenite dike, Isenhour Quarry, Cabarrus County, N.C.	do	262	49	450±50 L
	IPA	Gneissic granodiorite, Isenhour Quarry, Cabarrus County, N.C.	do	132	28	505±55 L
	IPB	do	do	123	25.5	495±55 L
	IPC	do	do	117	19	380±100 L
	IPD	do	do	132	26	470±55 L
24	50-L-174	Mica schist, at bridge 2.6 miles northeast Bessemer City, Gaston County, N.C.	do	620	127	490 E

See footnotes at end of table.

TABLE 7.—*Lead-alpha age determinations on zircon and monazite from North and South Carolina*—Continued

Sample locality on plate 4	Field No.[1]	Rock type and locality	Mineral	Alpha per mg per hr	Average lead content from duplicate determinations (ppm)	Calculated age (millions of years) [2]
25	56-OT-11	Coarse-grained augite syenite, quarry 2.5 miles south of Concord, Cabarrus County, N.C.	Zircon	24	3.0	305 } 425±110 L
	56-OT-11a	do	do	22	5.0	540 }
26	59-OT-111 (NM 1.5).	Porphyritic granite exposed on county road between Watts and S.C. Rt. 71 at a point 2 miles south of Rt. 71, Abbeville County, S.C. Nonmagnetic fraction at 1.5 amperes in Frantz Separator.	do	344	82	565±65 L
	59-OT-111 (M 1.5).	Same sample, magnetic at 1.5 amperes.	do	481	102	505±55 L
27	USNM 97589.	Large zircon crystals from biotite gneiss, 4.5 miles east of Iva, at line between Abbeville County and Anderson County, S.C.	do	172	40	550±60 L
28	56-OT-13	Sericite schist of Battleground Schist, 1.5 miles southeast of the Pinnacle, Gaston County, N.C.	do	78	33.5	980±110 L

[1] Samples in the:
48-OT, 49-OT, 50-OT, 53-OT, 54-OT, and 59-OT series collected by W. C. Overstreet.
56-OT series and IP series collected by W. C. Overstreet and Henry Bell, 3d.
HB-59 series collected by Henry Bell, 3d.
50-Y series collected by R. G. Yates.
50-L series and 55-NC series collected by W. R. Griffitts.
USNM series from the collection of the U.S. National Museum.
53-BE series collected by P. B. Benson and A. M. White.
47-MT series collected by J. B. Mertie, Jr.
Samples:
60-OT-1000 and 60-OT-1001 collected by J. W. Whitlow.
60-OT-1002 collected by H. S. Johnson, Jr.

[2] Lead-alpha ages were calculated from the equations:

$$t=\frac{C\times Pb}{\alpha},$$

where t is the calculated age in millions of years, C is a constant based upon the Th/U ratio and has a value of 2485 for zircon and 2085 for monazite, except uranium-rich monazite in 53-BE-3 where C as determined by analysis is 2375, Pb is the lead content in parts per million, and α is the alpha counts per milligram per hour; and

$$T=t-\frac{1}{2}kt^2,$$

where T is the age in millions of years corrected for decay of uranium and thorium, and k is a decay constant based upon the Th/U ratio and has a value of 1.56×10^{-4} for zircon and 0.65×10^{-4} for monazite.
Ages are rounded off to the nearest 5 my. Errors shown are due only to the uncertainties in the analytical techniques in measurement of lead content and alpha activity of the samples.

[3] Single determination.

Analytical procedures have been revised (Rose and Stern, 1960; Stern and Rose, 1961, p. 606); therefore, the age determinations in table 7 include an early group of analyses marked E and a late group marked L. No sample in table 7 has been analyzed by both methods. Each method gives ages that fall into four general groups in apparent agreement with observed field relations (table 8), but some analyses by each method have given apparent ages that conflict with field relations. Eleven conflicting ages are shown among the 53 listed in table 8. The agreement of the lead-alpha ages with the field data now available seems to increase with decreasing age of the rocks.

TABLE 8.—*Correlation of lead-alpha ages of minerals with the geologic position of the host rocks*

Lead-alpha age: Boldface indicates ages in conflict with observed field relations.
Mineral: M, monazite; Z, zircon.

Era	Period	Intrusive episode and sequence of sedimentary and pyroclastic rocks	Rock	Sample locality on plate 4	Field No.	Lead-alpha age (millions of years)	Mineral
Mesozoic	Triassic		Diabase dikes				
			Sandstone and shale				
Unconformity							
Paleozoic	Probably Mississippian through Permian	C, upper sequence	Vermiculite pegmatite.	1	USNM 105674	255±30	Z
			do	1	60-OT-1001	270±30	Z
			do	1	60-OT-1002	260±30	Z
			Syenite pegmatite	2	USNM 80114	280±30	Z
			do	2	60-OT-1000	300±45	Z
			Cherryville Quartz Monzonite.	3	53-BE-3	260	M
			Yorkville Quartz Monzonite.	4	54-OT-225	260	Z
			Biotite granite	5	59-OT-101	255±30	Z
			do	7	59-OT-102	270±30	Z
			Granite	8	59-OT-107	260±30	Z
			Biotite granite	9	59-OT-110	245±30	Z
			do	6	59-OT-100	**460±50**	Z
			Syenite dike	23	HB-39-59	**450±50**	Z
			Augite syenite	25	56-OT-11	**305** } **425±110**	Z
			do	25	56-OT-11a	**540**	Z
			Battleground Schist	28	56-OT-13	**980±110**	Z
	Unconformity (probably between Devonian and Mississippian)						
	Probably Ordovician through Devonian	B, middle sequence	Toluca Quartz Monzonite.	10	47-MT-73	**320**	M
			Toluca Quartz Monzonite, late phase.	13	54-OT-221	**300**	Z
			Biotite granite	23	IPH	**300±30**	Z
			Toluca Quartz Monzonite.	11	49-OT-14	440	Z
			Toluca Quartz Monzonite, late phase.	12	49-OT-22	375	M
			Pegmatite related to Toluca Quartz Monzonite.	11	49-OT-16	425	Z
			do	11	49-OT-16b	435	Z
			do	11	49-OT-16	380	M
			do	11	53-OT-14	375	M
			do	11	53-OT-14	455	Z
			Henderson Gneiss	18	54-OT-207	355	Z
			Biotitic Whiteside Granite.[1]	19	55-NC-5	370	M
			do	20	55-NC-4	415	M
			Muscovitic Whiteside Granite.[1]	20	55-NC-3	440	M
			Biotitic Whiteside Granite.[1]	22	55-NC-7	360	M
			Biotite granite	23	IPE	445±50	Z
			do	23	IPF	360±50	Z
			do	23	IPG	430±50	Z
			Biotite-hornblende-oligoclase gneiss.	14	50-Y-328	355	Z
			do	14	50-Y-328	400	M
			Biotite schist	15	48-OT-81A	420	Z
			do	15	48-OT-81A	390	M
			do	15	48-OT-81	395	Z
			do	16	50-Y-538	395	M
			do	17	50-OT-441	415	M
			Muscovitic Whiteside Granite.[1]	20	55-NC-3	**710**	Z
			Biotitic Whiteside Granite.[1]	22	55-NC-7	**670**	Z

See footnote at end of table.

TABLE 8.—*Correlation of lead-alpha ages of minerals with the geologic position of the host rocks*—Continued

Era	Period	Intrusive episode and sequence of sedimentary and pyroclastic rocks	Rock	Sample locality on plate 4	Field No.	Lead-alpha age (millions of years)	Mineral
	-Unconformity (probably between Cambrian and Ordovician)-						
	Cambrian and Late Precambrian(?)	A, lower sequence	Gneissic granodiorite.	23	IPC	380±100	Z
			-----do-----	23	IPA	505±55	Z
			-----do-----	23	IPB	495±55	Z
			-----do-----	23	IPD	470±55	Z
			Porphyritic granite	26	59-OT-111 (NM 1.5)	565±65	Z
			-----do-----	26	59-OT-111 (M 1.5)	505±55	Z
			Biotite gneiss	27	USNM 97589	550±60	Z
			Mica schist	24	50-L-174	490	Z
	-Unconformity (unobserved in the Piedmont of South Carolina)-						
Precambrian	Precambrian	Basement sequence (unobserved in the Piedmont of South Carolina)	Biotite schist	21	55-NC-2	620	Z
			-----do-----	21	55-NC-2	590	Z

[1] Structurally not in the middle sequence, but intrusive episode thought to be equivalent to intrusive episode of the middle sequence in the Piedmont.

Rocks in the upper sequence are represented by 15 samples of zircon and one sample of monazite. The lead-alpha ages of 10 samples of primary zircon and the sample of primary monazite from intrusive rocks in the sequence range from 245 to 300 my. The average lead-alpha age of the 10 zircon samples is 265 my; the age of the monazite is 260 my. The ages of five samples of zircon from three other intrusive rocks and one pyroclastic rock in the sequence range from 305 to 980 my. There is no known reason for the old apparent ages of two of the five samples of zircon, but the other old apparent ages result from poor choice of sample material. Two determinations were made on primary zircon (56–OT–11 and 56–OT–11a) that has very little lead and low alpha activity; hence, the apparent old ages may result from analytical error. The oldest apparent age, 980±110 my, was determined on detrital zircon in a pyroclastic rock.

We interpret the pattern of lead-alpha ages found for primary zircon and monazite to indicate that the intrusive rocks in the upper sequence are about 260 my old (rounded to nearest 10 my). The age is similar to the K^{40}/Ar^{40} age of micas—≈250 my, obtained by Long, Kulp, and Eckelmann (1959, p. 597)—formed during the orogeny at the end of the Paleozoic Era in the Southeast.

Rocks in the middle sequence are represented by 15 samples of zircon and 12 samples of monazite (table 8). Twenty of the rocks sampled are believed to be intrusive; seven are probably metasedimentary or metavolcanic rocks. The apparent lead-alpha ages of 11 samples of zircon average 410 my—8 samples average 430 my, and 3 samples average 360 my. Eleven samples of monazite have an average apparent lead-alpha age of 390 my. Two samples of zircon and one sample of monazite have the anomalously young apparent ages of 300–320 my, and two samples of zircon have the old apparent ages of 670 and 710 my. We do not know the reason for the anomalously young apparent ages of the zircon and monazite, but we think that the old apparent ages are of relict detrital zircon.

Comparison betwen the lead-alpha ages in table 8 and the isotopic ages in table 9 indicates that the average apparent lead-alpha ages of 410 my for zircon and 390 my for monazite in table 8 are minimal. The actual age of the main plutonic event in the middle sequence is probably closer to 450 my than to 400 my (Grunenfelder and Silver, 1958).

Rocks in the lower sequence are represented by eight samples of zircon that have apparent lead-alpha ages ranging from 380 to 565 my. The zircon dated at 380 my and three other samples that have apparent lead-alpha ages between 470 and 505 my were collected from the same rock in the same exposure. Therefore, the youngest of the eight determinations is here interpreted to be incorrect. For the seven other determinations, the average apparent lead-alpha age is 510 my. At present, no data are available to aid in evaluating this group of lead-alpha ages. Field evidence suggests that the rocks from which these zircon crystals came occupy positions low in the exposed part of the stratigraphic sequence in South Carolina. They therefore have been involved in several episodes of metamorphism, and the apparent age is probably minimal. Possibly these zircon crystals are at least 550 my.

The oldest rocks exposed in South Carolina are the schists and gneisses in the Blue Ridge belt. Minerals from these rocks in South Carolina have not been studied with respect to age. Two of the samples of zircon indicated in table 8 are from exposures of the rocks in North Carolina, and a number of samples indicated in table 9 are from rocks in North Carolina and Tennessee. The lead-alpha ages of the two samples of zircon indicated in table 8 resemble some of the 16 discordant isotopic ages of zircon crystals indicated in table 9, which are from 360 to 1,270 my, but mostly between 670 and 940 my. These ages are minimal. They are the result of a succession of geologic events following the principal plutonic episode that affected these old rocks. This episode has been shown by Davis and others (1958, p. 178) to have occurred at about 1,100 my.

We have interpreted the field relations of the rocks from which the zircon and monazite were taken to show that the rocks are related to one or another of three orogenic episodes called A, B, and C in tables 2, 3, and 4, or to a basement complex. The apparent close relation between the stratigraphic succession in South Carolina (table 2) and the four age groups of minerals (table 8)—about 260, 450, 550, and 1,100 my—and the ages assigned to the geologic periods (table 6) lead us to infer that the basement complex in South Carolina is earlier Precambrian and that the rocks of episodes A, B, and C are later Precambrian(?) and Paleozoic. The three orogenic episodes seem to have been accompanied by metamorphic-plutonic events focused in Cambrian (episode A), Ordovician (episode B), and Permian time (episode C), as measured by the Holmes scale of 1959 (Holmes, 1959, p. 204). Silurian and Devonian events may have affected the rocks formed in the episode which climaxed in Ordovician time (table 8). Mississippian and Pennsylvanian events are probably included in episode C, which climaxed in Permian time. More precise distinctions cannot be made with the available data.

The two unconformities observed by us in the metasedimentary rocks (tables 2, 3, 4; pl. 3) are very broadly bracketed by episodes A, B, and C. The earlier of the two, the unconformity between episodes A and B, probably represents a period of uplift and erosion that culminated an orogeny in Cambrian time. The younger unconformity, between episodes B and C, is probably younger than the last intrusions of granite in episode B and older than the youngest rocks intruded by the granite, gabbro, and syenite plutons of Permian age. It possibly represents uplift that began late in Devonian time and extended into the Carboniferous.

After the close of the Appalachian orogeny, the roofs of the Permian plutons in South Carolina were exposed by erosion and partly covered by sandstone and shale of Late Triassic age. These sedimentary rocks were intruded by diabase dikes of Late Triassic(?) age. Dikes and flows of similar geologic association in Virginia, Pennsylvania, and Nova Scotia have tentatively been dated by Hurley and Goodman (1943, p. 309) as 158–174 my old; these ages are based on the abundance of helium in magnetite. The ages are in the range of ages given to the Jurassic period by Holmes (1959, p. 204). The age of the Palisades diabase sill, which in New Jersey intrudes the Newark Group of Late Triassic age, has been reported by Erickson and Kulp (1961, p. 650–651) to be about 190–200 my by K^{40}/Ar^{40} methods. This age is in the range of ages given by Holmes (1959, p. 204) for the Triassic period. The diabase dikes in South Carolina have not been dated by age determinations, but they may be about the same age as the Palisades sill or somewhat younger.

TABLE 9.—*Mineral age determinations in relation to the ages of the crystalline rocks of South Carolina*

[Field No: Leaders indicate none]

Sample locality on plate 4	Field No.	Source	Mineral or rock	Age of mineral in millions of years						Reference
				U^{238}/Pb^{206}	U^{235}/Pb^{207}	Pb^{207}/Pb^{206}	Th^{232}/Pb^{208}	Rb^{87}/Sr^{87}	K^{40}/Ar^{40}	
29		Vein. Marietta, Greenville County, S.C	Uraninite	[1]320						Rodgers (1952, p. 419).
30	L-120P	Gaffney Marble, Gaffney, Cherokee County, S.C.	Phlogopite						309±11	Long and others (1959, p. 595).
31	L-124B	Granite, Cayce, Lexington County, S.C	Biotite						226±9	Do.
	L-124B	do	do						233±9	Do.
32	L-125B	Granite, Elberton, Elbert County, Ga	do						247±9	Do.
	B-3177	do	do					254±13	345±20	Pinson and others (1957, p. 1781).
	M3177	do	Muscovite					245±13		Do.
33		Granite, Comolli Quarry, Elbert County, Ga.	Zircon	450	455	465	375			Grunenfelder and Silver (1958, p. 1574).
		Granite, saprolite, Elbert County, Ga	do	490	480	415	380			Do.
34		Henderson Gneiss near Hendersonville, Henderson County, N.C.	Gneiss						260	Carr and Kulp (1957, p. 776).
35		Pegmatite, Chestnut Flat Mine, Spruce Pine district, N.C.	Uraninite	385	390	400±50				Aldrich and others (1958, p. 1128).
		do	do	370	375	420±50				Do.
		do	Muscovite					375	335	Do.
		do	Potassium feldspar.					385		Do.
36	K-4	Pegmatite, Wiseman Mine, Spruce Pine district, N.C.	Samarskite	307±6	312±13	380±80	205±50			Eckelmann and Kulp (1957, p. 1124).
	K-3	Pegmatite, Spruce Pine district, Mitchell County, N.C.	do	282±13	292±17	405±60	170±10			Do.
		do	Uraninite			355±20				Do.
37	K-105	Pegmatite, Flat Rock Mine, Spruce Pine district, N.C.	do	344±4	346±5	372±15				Do.
	K-121	do	Gummite			355±20				Do.
	K-96-1	Pegmatite, McKinney Mine, Spruce Pine district, N.C.	Samarskite	367±18	353±20	300±40	400±80			Do.
	K-96-2	do	do	314±10	316±10	342±20	302±30			Do.
		do	Muscovite						329	Carr and Kulp (1957, p. 776).
		do	do						346	Do.
		do	Feldspar						231	Do.
		do	do						242	Do.
38		Pegmatite, Hoot Owl Mine, Spruce Pine district, N.C.	do						278	Do.
		do	Muscovite						332	Do.

39		Pegmatite, Minpro Mine, Spruce Pine district, N.C.	do						338	Do.
		do	Feldspar						248	Do.
40	L-139M	Pegmatite, Gay, Jackson County, N.C.	Muscovite						348±13	Long and others (1959, p. 594).
41	L-136M	Pegmatite, Bryson City, Swain County, N.C.	do						340±13	Do.
37	L-30M+B	Gneiss, McKinney Mine, Spruce Pine district, N.C.	Muscovite and biotite						341±13	Do.
		Gneiss, near McKinney Mine, Spruce Pine district, N.C.	Gneiss						378	Carr and Kulp (1957, p. 776).
42	L-141B	Gneiss, near Stocksville, Buncombe County, N.C.	Biotite					330±13	357±13	Long and others (1959, p. 587, 594).
40	L-140B	Gneiss, near Gay, Jackson County, N.C.	do					333±15	438±14	Do.
43		Gneiss, Mortimer, Caldwell County, N.C.	Zircon	800	860	1020	670			Tilton and others (1959, p. 174).
44		Granite gneiss, Crossnore, Avery County, N.C.	do	690	720	800	680			Do.
45	L-119M	Alaskite near Lincolnton, Lincoln County, N.C.	Muscovite						315±11	Long and others (1959, p. 595).
46		Large zircon float, near Statesville, Iredell County, N.C.	Zircon	[2]355						Larsen and others (1949, p. 27).
47	L-146B	Cranberry Gneiss, Roan Mountain, Carter County, Tenn. ter County, Tenn.	Biotite						357±13	Long and others (1959, p. 594).
48	L-333B	Cranberry Gneiss, near Hopson, Carter County, Tenn.	do						527±18	Do.
	L-332B	do	do					719±25	640±22	Long and others (1959, p. 594, 587).
49	L-331B	Cranberry Gneiss, near Hampton, Carter County, Tenn.	do						648±22	Long and others (1959, p. 594).
	L-328B	do	do					892±30	674±22	Long and others (1959, p. 594, 587).
	L-149B	Cranberry Gneiss, Pardee Point, Carter County, Tenn.	do						800±27	Long and others (1959, p. 594).
50	L-330B	Cranberry Gneiss, near White Rock, Carter County, Tenn.[3]	do						695±23	Do.
36		Cranberry Gneiss, Deyton Bend, Spruce Pine district, N.C.	Zircon	1080	1140	1270	950			Davis and others (1958, p. 178); Tilton and others (1959, p. 174).
		do	Biotite					350	322	Do.
49		Cranberry Gneiss, Pardee Point, Carter County, Tenn.	Zircon	670	735	940	360			Tilton and others (1959, p. 174).
		do	Biotite					900	780	Do.

[1] Age determined by chemical analysis of total uranium and lead.
[2] Age determined by lead-alpha method of analysis.
[3] Given as White Rock, N.C., in source, but White Rock is between Hopson and Roan Mountain, Tenn.

Further erosion and sedimentation in Mesozoic and Cenozoic time produced the Piedmont surface and Coastal Plain of South Carolina as we now see them. Igneous activity in the Piedmont may not have ceased with the emplacement of the Late Triassic(?) diabase dikes. Bentonitic clays of Eocene age in sediments of the Coastal Plain in northwestern Orangeburg County and western Calhoun County, S.C., about 20 miles south of Columbia, were being investigated in 1960 by S. D. Heron, Jr. (Johnson, 1961, p. 2, 4). The clay contains sharply terminated crystals of euhedral zircon and appears to have been derived from volcanic ash. Similar possible pyroclastic deposits of Miocene(?) age are known in Jasper County, S.C. (H.S. Johnson, Jr., 1961, written commun.). The rather small size and sporadic occurrence of the bentonite deposits suggest that the ash came from local vents. Dikes have not been observed in sedimentary rocks of those ages in the Coastal Plain. Possibly some of the rhyolite dikes in the Piedmont are Eocene or Miocene in age and supplied ash to the Coastal Plain. Another possible source for the ash is sea mounts off the Atlantic coast (Drake, Ewing, and Sutton, 1959, p. 175–181).

AGE OF SPECIFIC ROCK UNITS

The ages of the minerals listed in tables 7, 8, and 9 have been shown to be mainly minimal and subject to interpretation. The mapped position of the host rock in the stratigraphic succession and in the sequence of plutonic episodes as interpreted for the crystalline rocks of South Carolina and adjacent parts of North Carolina provides the relative time sequence against which we have evaluated the apparent ages.

LOWER SEQUENCE IN THE PIEDMONT

The lead-alpha ages of zircon (samples 59–OT–111 and USNM 97589) at localites 26 and 27 (pl. 4, table 7)—505, 550, and 565 my—suggest that the metasedimentary rocks into which the porphyritic granite and biotite gneiss were intruded are at least Cambrian and possibly Precambrian in age. Because of the range in age that attaches to the determinations and because of the likelihood that the three ages are minimal owing to metamorphism following the initial crystallization of the zircon, it is possible that the granite and gneiss are also Precambrian in age. These possibilities are supported by the position of the porphyritic granite and biotite gneiss in the inferred stratigraphic succession in South Carolina (table 2). From this position and the apparent ages of the zircon, the lower sequence is here interpreted to include metamorphosed sedimentary and plutonic igneous rocks that are late Precambrian(?) in age.

The granitoid gneiss unit of the Charlotte belt includes gneissic granodiorite. This rock is well exposed in Cabarrus County, N.C. (loc. 23, pl. 4; Bell and Overstreet, 1959, fig. 1). Lead-alpha ages of four samples of zircon from the gneissic granodiorite (IPA, IPB, IPC, and IPD, tables 7 and 8) are 505, 495, 380, and 470 my; and the average apparent age of the three older zircon samples is 490 my. Although the rock was metamorphosed after it crystallized, the metamorphism was of low grade and may have only slightly altered the age of the zircon. In the time scale, 490 my is close to the border between Ordovician and Cambrian time (table 6). The geologic relations indicate that Cambrian is the most probable age for the gneissic granodiorite in the granitoid gneiss unit.

Zircon (50–L–174, tables 7 and 8) from a schistose rock 2.6 miles northeast of Bessemer City, N.C. (loc. 24, pl. 4) is 490 my in age. The geologic relations of the rock are in doubt. It was originally mapped by Sterrett (1912, map) as Bessemer Granite; but the Bessemer Granite was shown by Espenshade and Potter (1960, p. 70) to consist of biotite schist, biotite gneiss, and intrusive oligoclase tonalite. Because the zircon came from schist, it is probably older than the oligoclase tonalite; however, little is known about the relations, and we cannot regard the sample as contributing to our knowledge of the age of the rocks.

The few ages we have for intrusive rocks from episode A in the Piedmont suggest that the metasedimentary rocks in the lower sequence are late Precambrian(?) and Cambrian in age and that the intrusive rocks restricted to episode A are late Precambrian(?) to late Cambrian in age.

MIDDLE SEQUENCE IN THE PIEDMONT

Construction of the middle sequence of rocks in the Piedmont appears to have begun early in Ordovician time with the outpouring of mafic lava on the eroded surface of the lower sequence of sedimentary and pyroclastic rocks and to have closed in Late Devonian time with the emplacement of the last bodies of a large group of granitic rocks. Many of the masses of granite intruded into the middle sequence seem, on the basis of mineral ages, to be Late Ordovician in age. Some granitic rocks appear to have been formed from sedimentary rocks of the middle sequence during the strong metamorphism of episode B. At the time the middle sequence was being metamorphosed in the Piedmont, the basement rocks in the Blue Ridge belt were also again metamorphosed, and numerous large bodies of granitic rocks and swarms of pegmatites were formed there. As yet no mineral ages have been determined to date the first outpouring of mafic lavas in the middle sequence. Most mineral ages thus far determined appear to reflect the age of crystallization of the granitic rocks, the age of episode B metamorphism, or the metamorphism during episode C.

TOLUCA QUARTZ MONZONITE

Lead-alpha and isotopic age determinations have been made on minerals from the Toluca Quartz Monzonite and genetically related pegmatite rocks at four localities in North Carolina (10, 11, 12, and 13, pl. 4). Of the five samples of zircon from this rock (49–OT–14, 49–OT–16, 49–OT–16b, 53–OT–14, and 54–OT–221, tables 7 and 8), four range in lead-alpha age from 425 to 455 my and have an average age of 440 my. The fifth (54–OT–221) has a lead-alpha age of 300 my. The difference may result from an error in the determination of the lead. Three samples of monazite (49–OT–16, 49–OT–22, and 54–OT–14, tables 7 and 8) are virtually identical in age at 375 my. One sample (47–MT–73) gives a lead-alpha age of 320 my, which is probably also due to an inaccurate determination of the lead.

Isotopic ages of zircon and biotite from the Toluca Quartz Monzonite at the Acre Rock quarry, Cleveland County, N.C. (loc. 11, pl. 4) were made by G. R. Tilton, who reported (written commun., 1960):

	Age in millions of years			
	U^{238}/Pb^{206}	U^{235}/Pb^{207}	Pb^{207}/Pb^{206}	Rb^{87}/Sr^{87}
Zircon	405 ± 10	415 ± 10	480 ± 50	----------
Biotite	----------	----------	----------	250 ± 10

From these data we conclude that the lead-alpha ages of the zircon are closer to the age of initial crystallization of the Toluca Quartz Monzonite than are the lead-alpha ages of the monazite. The probable age of the Toluca Quartz Monzonite may be about 450 my, but at 250 my the rock was metamorphosed, with recrystallization of the biotite and modification of the monazite.

Lead-alpha ages have been determined for three samples of zircon (48–OT–81A, 48–OT–81, and 50–Y–355, tables 7 and 8) and four samples of monazite (48–OT–81A, 59–Y–328, 50–Y–538, and 50–OT–415, tables 7 and 8) from biotite schist and biotite gneiss of upper amphibolite facies exposed in the same area (locs. 14, 15, 16, and 17, pl. 4) as the Toluca Quartz Monzonite. The zircon ranges from 355 to 420 my in age, and averages 390 my. Ages of the monazite grains range from 390 to 415 my and average 400 my. We think that the zircon is detrital and that original radiogenic daughter products diffused from it during the high-grade metamorphism of episode B. During episode B the monazite crystallized as a metamorphic mineral (Overstreet, 1960). Evidently, both the zircon and the monazite were also affected by the metamorphic event of episode C and have an apparent age younger than the age of plutonism in episode B.

A lead-alpha age of 355 my was determined for large zircon crystals that occur as float near Statesville, N.C. (loc. 46, table 9 and pl. 4; Larsen and others 1949, p. 27–28). Although the locality is within the Inner Piedmont belt, the geologic occurrence of the sample is not certain. The zircon crystals are as much as 3 inches across (Pratt, 1916, p. 17); therefore, they could not be relict detrital grains in schist but probably had a source in pegmatite, perhaps syenite pegmatite.

UNNAMED GRANITES IN THE INNER PIEDMONT AND CHARLOTTE BELTS

Unnamed granites in the Inner Piedmont belt and Charlotte belt in Anderson and Abbeville Counties, S.C., adjacent to Elbert County, Ga., may be similar in age to the granite exposed around Elberton, Ga. (locs. 32 and 33, pl. 4). Eight isotopic ages (table 9) determined for two samples of zircon from granite near Elberton range from 375 to 490 my (Grunenfelder and Silver, 1958, p. 1574). The zircon crystals from this granite are probably at least 440 my old, but the relations are not well enough known to determine whether the age of the zircon is the age of original crystallization of the granite or the resultant of several processes that have operated during the history of the rock. Rb^{87}/Sr^{87} ages of biotite and muscovite from the granite are 254 my and 245 my, and a K^{40}/Ar^{40} age of the biotite is 345 my (Pinson and others, 1957, p. 1781). Other K^{40}/Ar^{40} ages for the biotite in the granite at Elberton are 233 my and 247 my (Long, Kulp, and Eckelmann, 1959, p. 595). Ages of the zircon and mica closely resemble ages for the same minerals in the Toluca Quartz Monzonite.

A lead-alpha age of 460 my was found for zircon (59–OT–100, tables 7 and 8) from granite in Chester County, S.C. (loc. 6, pl. 4). Field relations were previously interpreted (Overstreet and others, 1961) as showing that the granite is part of an episode C pluton. However, we now think that it is possible that this zircon came from older granite adjacent to the young pluton.

Very similar lead-alpha ages were found for three out of four samples of zircon (IPE, IPF, IPG, and IPH, tables 7 and 8) from biotite granite in Cabarrus County, N.C. (loc. 23, fig. 4). The three ages—445, 360, and 430 my—resemble ages of zircon from the Toluca Quartz Monzonite and from granite at Elberton, Ga.

HENDERSON GNEISS

Zircon (54–OT–207, tables 7 and 8; loc. 18, pl. 4) from porphyritic Henderson Gneiss at the east edge of the main mass of gneiss (Stuckey and Conrad, 1958, map) about 10 miles southeast of the Brevard fault has a lead-alpha age of 355 my. A K^{40}/Ar^{40} age of 260 my was determined by Carr and Kulp (1957, p. 776, 780–781) on a bulk sample of Henderson Gneiss from the type locality in the vicinity of Hendersonville, N.C. (loc. 34, table 9 and pl. 4). This area is in a strongly sheared part of the gneiss about 7 miles southeast of the Brevard fault. We think that the K^{40}/Ar^{40} age probably reflects the metamorphism of episode C, also shown by biotite from the Toluca Quartz Monzonite and by biotite from granite at Elberton, Ga.

The age of the Henderson was originally given by Keith (1905, p. 4) as Precambrian and modified by Reed (1964) to Precambrian or early Paleozoic. The unit in South Carolina appears to be interbedded with sedimentary rocks of the middle sequence and is, therefore, here interpreted to be no older than Ordovician and no younger than Devonian.

BIOTITE GRANITE GNEISS

The age of uraninite from a vein in the biotite granite gneiss unit of the Inner Piedmont belt exposed near Marietta, S.C. (loc. 29, table 9 and pl. 4) was estimated by Rodgers (1952, p. 419) from an old chemical analysis to be 320 my. No relation between the origin of the vein and the origin of the biotite granite gneiss is known, but the presence of the vein does place a minimum age on the gneiss. We have interpreted other field relations to indicate that the biotite granite gneiss may be about the same age as, or somewhat younger than, the Henderson Gneiss.

WHITESIDE GRANITE

Four samples of monazite (55–NC–3, 55–NC–4, 55–NC–5, and 55–NC–7, tables 7 and 8) and two samples of zircon (55–NC–3 and 55–NC–7) from exposures of the Whiteside Granite in the Blue Ridge belt in Jackson and Macon Counties, N.C. (locs. 19, 20, and 22, pl. 4), show distinctly different lead-alpha ages. The ages of the monazite range from 360 to 440 my and average 400 my. The two samples of zircon are 670 and 710 my in age.

The wallrocks of the Whiteside Granite are schists and gneisses of the staurolite-kyanite subfacies of regional metamorphism. They are polymetamorphic rocks whose minerals appears to have had a complex history of metamorphic modification and recrystallization following an initial plutonic metamorphism at about 1,100 my. (Long, Kulp, and Eckelmann, 1959, p. 588). Lead-alpha ages of two samples of zircon (55–NC–2, tables 7 and 8) from a point 6.3 miles east of Franklin, Macon County, N.C. (loc. 21, pl. 4) are 620 and 590 my.

A K^{40}/Ar^{40} age of biotite (L–140B, table 9) from gneiss near Gay, Jackson County, N.C. (loc. 40, pl. 4), is 438 my (Long, Kulp, and Eckelmann, 1959, p. 594). Both the lead-alpha and K^{40}/Ar^{40}

ages are considerably younger than the probable age of initial metamorphism of the schist and gneiss, and the K^{40}/Ar^{40} age, at least, reflects a later metamorphism (Long, Kulp, and Eckelmann, 1959, p. 590).

Difference in age between the monazite in the Whiteside Granite (average 400 my) and the biotite in the gneiss at Gay, N.C. (438 my), is not as great as the difference in age between the monazite and the zircon in the Whiteside Granite. The zircon in the Whiteside is closer in age to the zircon in the wallrocks than it is to the monazite in the Whiteside. From these relations, two possible interpretations emerge. The Whiteside Granite may be Precambrian in age, and the apparent age of its monazite was reduced when the area underwent later metamorphism. During this metamorphism, the age of the biotite in the wallrocks was also reduced. The second possibility, and the one we favor, is that the Whiteside Granite formed by granitization of the Blue Ridge schist and gneiss as the result of a metamorphic event whose minimum age is 400 my. Under this interpretation, the Whiteside Granite formed at the staurolite-kyanite subfacies of regional metamorphism; its monazite crystallized during this metamorphism; and its zircon is relict but not completely cleared of earlier formed radiogenic daughter products. We think, therefore, that the Whiteside Granite is older than Carboniferous(?), as it was called by Keith (1907, p. 4). We think that it is younger than Cambrian but no younger than Devonian. The apparent lack of late metamorphic effects on the Whiteside Granite was interpreted by Keith (1907, p. 4–5) to indicate that the rock is as young as Carboniferous. We think that it shows that the granite is not Precambrian. The minimum age of the Whiteside Granite seems to us to be about 400 my.

The relations between the ages of monazite and zircon in the Whiteside Granite and its wallrocks are interpreted by us to show that relict zircon in polymetamorphic rocks is not cleared of earlier formed radiogenic daughter products unless the grade of the late metamorphism exceeds the staurolite-kyanite subfacies. Where the grade of regional metamorphism reaches the sillimanite-almandine subfacies, however, as in the core of the Inner Piedmont belt, relict zircon is cleared of earlier radiogenic daughter products.

MUSCOVITE-PERTHITE PEGMATITE

The ages of minerals from the muscovite-perthite pegmatite dikes in the Blue Ridge belt in South Carolina have not been measured, but a great many ages have been determined on a variety of minerals from very similar pegmatites in the Blue Ridge of North Carolina. We think that these commercial muscovite pegmatite dikes in the Blue

Ridge belt in South Carolina probably formed at the same time that the sheet-muscovite-bearing pegmatite dikes formed in the Cashiers district, Transylvania and Jackson Counties, N.C., and at nearly the same time as those in the Franklin-Sylva district, N.C. (locs. 21 and 40, pl. 4), the Bryson City district, N.C. (loc. 41, pl. 4), and the Spruce Pine district, N.C. (locs. 35–39, pl. 4). Although there seem to be small differences in the ages of muscovite-perthite pegmatites in these districts, their emplacement generally appears to have followed closely the formation of the Whiteside Granite.

In their admirable and comprehensive description of major metamorphic events in the southeast, Long, Kulp, and Eckelmann (1959, p. 588–597) attached critical significance to the observation that pegmatites at Spruce Pine have been unaffected by metamorphism since they were emplaced and that the age of their crystallization is about 350 my (Kulp and Poldervaart, 1956, p. 401–403; Wilcox and Poldervaart, 1958, p. 1364). Long, Kulp, and Eckelmann (1959, p. 591) also recognized a somewhat older metamorphism in the Ocoee Series at Ducktown, Tenn., where a minimum apparent K^{40}/Ar^{40} age for metamorphic biotite is 435 my, and they recognized a younger metamorphism (p. 592, 597) centering at about 250 my in the Piedmont of Georgia and South Carolina.

Recent field studies by Bryant and Reed (1960, p. 3–4), showed that the pegmatites at Spruce Pine have been cataclastically deformed and recrystallized, probably in a late stage of the same metamorphic pulse in which they were formed. The possibility that the cataclastic deformation of the pegmatites might have occurred at the same time as metamorphic episode C, at about 250 my, does not seem to be entertained by Bryant and Reed. However, we think metamorphic episode C may be responsible for some of the deformation and apparent mineral ages in the Blue Ridge.

The minerals from the pegmatite dikes in the Spruce Pine district (locs. 35–39, table 9), the Bryson City district, and the Franklin-Sylva district do not display a high degree of concordant ages at 350 my, as might be expected if the dikes had been unaffected by a later metamorphic pulse. Instead, the ages show a considerable span, the magnitude of which depends partly on the kind of mineral dated and partly on the method of analysis. Variations in the apparent ages caused by differences in analytical methods obviously do not measure differences in the ages of the minerals, but variations in ages determined by the same method on different kinds of minerals indicate the possibility that the differences in apparent ages may relate to degree of susceptibility of the mineral to metamorphic diffusion.

Isotopic uranium-lead ages of uraninite appear to be the most reliable, and several are available from the Spruce Pine district. Two nearly concordant groups of analyses of uraninite from the Chestnut Flat Mine (loc. 35, table 9 and pl. 4) gave ages of 370–420 my (Aldrich and others, 1958, p. 1128); one nearly concordant group of analyses of uraninite from the Flat Rock Mine (loc. 37, table 9 and pl. 4) gave 344–372 my; and a single Pb^{207}/Pb^{206} analysis of uraninite from the Spruce Pine district gave an age of 355 my (Eckelmann and Kulp, 1957, p. 1124). Two groups of nonconcordant uranium-lead isotopic ages of samarskite from the Wiseman Mine (loc. 36, table 9 and pl. 4) and elsewhere in the Spruce Pine district gave ages of 282–405 my (Eckelmann and Kulp, 1957, p. 1124). Isotopic uranium-lead analyses of two samples of samarskite from the McKinney Mine (loc. 37, table 9 and pl. 4) gave nonconcordant ages of 300–367 my (Eckelmann and Kulp, 1957, p. 1124). One Pb^{207}/Pb^{206} analysis of gummite from the Flat Rock Mine (loc. 37, table 9 and pl. 4) gave an age of 355 my. Samarskite from this group of analyses appears to be less stable than uraninite and gives a younger apparent age. Pb^{207}/Pb^{206} ages of the samarskite from the Wiseman mine and an unspecified locality in the Spruce Pine district are, however, 380–405 my (Eckelmann and Kulp, 1957, p. 1124), which is close to the ages of the uraninite at the Chestnut Flat mine (Aldrich and others, 1958, p. 1128). We interpret these uranium-lead ages to indicate that the uraninite and samarskite in pegmatites at Spruce Pine crystallized as early as 400 my and were later modified.

Two Rb^{87}/Sr^{87} analyses of muscovite and potassium feldspar from the Chestnut Flat mine (loc. 35, table 9 and pl. 4) gave ages of 375 and 385 my, which tend to support an older age than 350 my for these pegmatite dikes.

Five K^{40}/Ar^{40} analyses of muscovite (table 9) averaged 336 my, and four K^{40}/Ar^{40} analyses of feldspar (table 9) averaged 250 my in samples from the Spruce Pine pegmatite dikes. These analyses seem to show argon loss from the muscovite and feldspar during a thermal rise following original crystallization of the minerals. The resultant ages of the muscovite point to a metamorphic event younger than 350 my as the cause of the argon loss. Retentivity of argon by the feldspar was shown by Carr and Kulp (1957, p. 778) to be poorer than the retentivity of the muscovite; thus, the geologic meaning of the average K^{40}/Ar^{40} age of the feldspar, 250 my, cannot be evaluated. However, there is a similarity between that apparent age and the probable age of the late metamorphic event in the Piedmont.

Muscovite from a pegmatite dike at Gay, N.C. (loc. 40, table 9 and pl. 4), in the Franklin-Sylva district, and muscovite from a pegmatite dike in the Bryson City district, N.C. (loc. 41, table 9 and pl. 4), have K^{40}/Ar^{40} apparent ages of 348 and 340 my (Long, Kulp, and Eckelmann, 1959, p. 594).

In our opinion, the ages of minerals found in the Spruce Pine district can be reinterpreted to show that the pegmatites crystallized at least 400 my ago. We interpret subsequent metamorphism at about 260 my to have differentially lowered the apparent ages of the minerals. If zircon is more stable than uraninite in regional metamorphism, then uranium-lead isotopic-age determinations on zircon from the Spruce Pine district might clarify the age pattern. No analyses of zircon from this district have been published.

UPPER SEQUENCE IN THE PIEDMONT

The upper sequence of metamorphosed sedimentary and pyroclastic rocks in the Piedmont of South Carolina includes the Gaffney Marble, called Cambrian in age by Keith and Sterrett (1931, p. 6), and the Battleground Schist of inferred late Precambrian age (Keith and Sterrett, 1931, p. 4–5). Two startlingly different mineral ages have been determined for these metasedimentary rocks.

Phlogopite (L–120P, table 9) from the Gaffney Marble at Gaffney, S.C. (loc. 30, pl. 4), was analyzed by Long, Kulp, and Eckelmann (1959, p. 595) and was found to have an apparent K^{40}/Ar^{40} age of 309 my. This and other similar ages obtained in dating rocks in the Piedmont were interpreted by them to be indicative of a metamorphic episode at about 250 my. However, the field evidence shows that the Gaffney Marble was regionally metamorphosed only once (Kesler, 1944, p. 763–764), and at that time the phlogopite was crystallized. After that metamorphism, the marble in the Gaffney area was subjected to a slight thermal rise when the Yorkville Quartz Monzonite and Cherryville Quartz Monzonite were intruded. The apparent K^{40}/Ar^{40} age seems to be the resultant of the original metamorphic age of the phlogopite formed during episode C and modified by slight thermal rise occasioned by the intrusion of the Yorkville and Cherryville. We infer that the rocks in the area where the phlogopite sample was collected were less affected by the thermal rise than were the rocks a few miles farther south. Therefore, the original metamorphic age of the phlogopite may not be much greater than the apparent K^{40}/Ar^{40} age. The Gaffney Marble is high in the stratigraphic sequence that we infer for the Kings Mountain belt. It is thought to be part of a sedimentary unit that unconformably overlies rocks of Ordovician to Devonian age; therefore, it cannot be Cambrian, as proposed by Keith and Sterrett (1931, p. 6). The sequence of rocks in which the Gaffney Marble was deposited is intruded by the Mississippian(?) to Permian(?) Cherryville Quartz Monzonite and the Permian Yorkville Quartz Monzonite. From these relations the Gaffney Marble is here interpreted to be Mississippian in age, because it is younger than rocks of Devonian age and older than an intrusive rock of Mississippian (?) to Permian (?) age.

A lead-alpha age of 980 my was determined for zircon (56–OT–13, tables 7 and 8) from low-grade schistose pyroclastic rock (Espenshade and Potter, 1960, pl. 7) in the Battleground Schist, Gaston County, N.C. (loc. 28, pl. 4). It is the oldest lead-alpha age for zircon from the Piedmont in the Carolinas and one of the oldest lead-alpha ages from the Southeastern States. Similar apparent lead-alpha ages were reported by Carroll, Neuman, and Jaffe (1957, p. 187) and by Stern and Rose (1961, p. 609) for detrital zircon from arenite in the late Precambrian Ocoee Series in the Great Smoky Mountains along the border between North Carolina and Tennessee. We interpret the zircon from the Battleground Schist to be detrital in origin and to have been relatively unaffected by Paleozoic metamorphic events. We think the zircon came from basement rocks exposed to erosion when the Battleground Schist was deposited and that its apparent age is unrelated to the deposition or metamorphism of the schist.

The Battleground Schist of Keith and Sterrett is here interpreted to consist of two units separated by an unconformity, as shown on the geologic map (Overstreet and Bell, 1965) and in table 4. The lower unit is interpreted to be part of the sericite schist in the middle sequence. The upper unit is the sericite schist beneath the quartzite in the upper sequence. Inasmuch as the middle and upper sequences are here interpreted to be Ordovician to Mississippian in age, the Battleground Schist is also interpreted to be Ordovician to Mississippian in age.

Other formations mapped by Keith and Sterrett (1931, maps) in the Kings Mountain belt and here included in the sericite schist unit shown on the geologic map (Overstreet and Bell, 1965) are schistose phases of the Bessemer Granite and the Blacksburg Schist. The Bessemer Granite was originally called Precambrian, and the Blacksburg Schist was said to be Cambrian in age. They are here interpreted to be part of the sedimentary sequences represented by the sericite schist unit and are, therefore, shown on the geologic map as Ordovician to Mississippian. The Kings Mountain Quartzite and its Draytonville Conglomerate Member, called Cambrian by Keith and Sterrett (1931, maps), are shown on the geologic map (Overstreet and Bell, 1965) as part of a quartzite unit to which we assign an age of Ordovician to Mississippian.

CHERRYVILLE QUARTZ MONZONITE

Plutons of Cherryville Quartz Monzonite intrude across the youngest unconformity in the crystalline rocks in the Piedmont (pl. 1). Lead-alpha analysis of uranium-rich monazite (53–BE–3, tables 7 and

8) from Cherryville Quartz Monzonite exposed in Cleveland County, N.C. (loc. 3, pl. 4), gave an apparent age of 260 my. A preliminary apparent lead-alpha age of 285 my for this monazite (H. W. Jaffe and David Gottfried, written commun., 1954) was used (Overstreet and Griffitts, 1955, p. 566) to assign a Devonian age to the Cherryville Quartz Monzonite according to the Holmes-Marble time scale (table 6). The lead-alpha age of 260 my (table 7), when compared with the time scale of 1959, indicates that the Cherryville Quartz Monzonite is younger than Devonian.

Samples of muscovite and biotite from the same outcrop from which the monazite was obtained were analyzed by G. R. Tilton (written commun., 1960) and gave Rb^{87}/Sr^{87} ages of 350 my and 375 my, respectively.

Clear coarse book muscovite (L–119M, table 9) from alaskite in gneiss exposed on North Carolina Route 150 about 2 miles south of Lincolnton, N.C. (loc. 45, pl. 4), was found by Long, Kulp, and Eckelmann (1959, p. 595 and 601) to have an apparent K^{40}/Ar^{40} age of 315 my. The muscovite was interpreted by them as being derived from ancient Precambrian Carolina Gneiss, and its apparent age was ascribed to superimposed metamorphism in late Paleozoic time. However, Lincolnton and the area along Route 150 south and southwest of the city is largely underlain by the main pluton of Cherryville Quartz Monzonite (Sterrett, 1912, map; Griffitts and Overstreet, 1952, fig. 1; Stuckey and Conrad, 1958, map). Clear coarse book muscovite does not occur in the Piedmont gneisses and schists of this area, but it is a distinctive mineralogic feature of late-phase dikes of quartz monzonite and pegmatite that are related to the Cherryville. We think that the book muscovite analyzed by Long, Kulp, and Eckelmann is from the Cherryville Quartz Monzonite or a related late-stage dike.

From this conflicting information it is not possible to ascribe a definite age to the Cherryville Quartz Monzonite. Inasmuch as the Cherryville in South Carolina cuts the youngest unconformity in the crystalline rocks and, in North Carolina, contains minerals which range in apparent age from 375 to 260 my, we think that it can be classed at its type locality in North Carolina as Mississippian(?) to Permian(?) in age according to the new time scale of Arthur Holmes (table 6); and we here extend this age to the Cherryville Quartz Monzonite in South Carolina.

YORKVILLE QUARTZ MONZONITE

The Yorkville Quartz Monzonite intrudes the youngest unconformity in the crystalline rocks in the Piedmont. Its age was interpreted by Keith and Sterrett (1931, p. 6) to be Late Carboniferous(?) because it was undeformed and therefore accompanied the last phases of the Appalachian orogeny. Espenshade and Potter (1960, p. 79–80, pl. 7) gave the age of the rock as Early Mississippian(?) because of structural relations and an apparent lead-alpha age of 260 my for sharply prismatic zircon (54–OT–225, tables 7 and 8) from an exposure 1.7 miles south-southeast of Henry Knob, S.C. (loc. 4, pl. 4). They referred the apparent age to the Holmes-Marble time scale (table 6). According to the new time scale, the apparent age of the zircon indicates that the Yorkville Quartz Monzonite is Permian. We adopt Permian as the age of the Yorkville Quartz Monzonite at its type locality of York (formerly Yorkville), York County, S.C.

UNNAMED GRANITE IN CIRCULAR PLUTONS

Unnamed granites crop out as distinctive circular plutons in the Charlotte belt and Carolina slate belt in South Carolina. At least two of the plutons intrude through the upper unconformity in the crystalline rocks (pl. 1). Lead-alpha ages have been determined for five samples of zircon from three plutons, and K^{40}/Ar^{40} ages have been obtained for two samples of biotite from a fourth pluton. Four of the five samples of zircon range in apparent age from 245 to 270 my and have an average apparent age of 260 my. One sample of zircon (59–OT–100) is 460 my old, and has been discussed in the subsection on the ages of unnamed granites in the Inner Piedmont and Charlotte belts. The apparent K^{40}/Ar^{40} ages of the two samples of biotite are 226 my and 233 my (Long, Kulp, and Eckelmann, 1959, p. 595).

One of the four samples of zircon (59–OT–100, tables 7 and 8) that have an average apparent lead-alpha age of 260 my comes from a pluton near Chester, S.C. (loc. 5, pl. 4). The age of this zircon is 255 my. We think that it is also the probable age of the pluton and that this granite is Permian in age (table 6).

Two samples of zircon (59–OT–102 and 59–OT–107, tables 7 and 8) are from the circular pluton near Winnsboro, S.C. (locs. 7 and 8, pl. 4). Their lead-alpha ages are 270 and 260 my. This pluton intrudes through the upper unconformity in the crystalline rocks (pl. 1). We think that the ages of these zircon crystals are also the age of the granite and that the granite near Winnsboro is Permian in age (table 6).

One sample of zircon (59–OT–110, tables 7 and 8) from a locality (9, pl. 4) south of Liberty Hill, S.C., has an apparent lead-alpha age of 245 my. The pluton from which this zircon came also intrudes through the upper unconformity in the crystalline rocks (pl. 1). We interpret the age of this zircon to be the age of the granite in the vicinity of Liberty Hill, which is Permian (table 6).

The apparent K^{40}/Ar^{40} ages measured by Long, Kulp, and Eckelmann (1959, p. 595) for biotite (L–124B, table 9) from granite exposed in a quarry at Cayce, S.C. (loc. 31, pl. 4), are younger than the apparent lead-alpha ages of zircon from the plutons in Fairfield and Kershaw Counties. The biotite is described (Long and others, 1959, p. 601) as shredded and disaggregated and as being much altered to chlorite, epidote, and zoisite. The groundmass of the rock is said to show some granulation. These observations suggest to us that the granite at Cayce was involved in high-angle normal faulting at the onset of the Late Triassic sedimentation in the Piedmont. Strong evidence for such faulting exists only a few miles southwest of Cayce (pl. 1). Cataclastic deformation of the biotite in Late Triassic faulting might have caused loss of argon and resulted in apparent ages intermediate between the original age of the biotite and the age of the Late Triassic cataclasis. The age of original crystallization of the biotite is unknown, but we interpret the field relations of the granite at Cayce as indicating that the granite was formed at about the same time as the plutons near Winnsboro and Liberty Hill. Partial obliteration during Late Triassic time of relations in rock having an original age of about 260 my might have led to the observed ages of 226 and 233 my, if Late Triassic faulting is assumed to have taken place about 200 my ago (table 6).

SYENITE AND SYENITE PEGMATITE

Dikes of syenite and syenite pegmatite associated with dikes of gabbro, pyroxenite, and norite are younger than all other igneous rocks in the Piedmont except the diabase dikes of Late Triassic(?) age, which intrude the syenite. A sample of zircon from augite syenite exposed in a quarry 2.5 miles south of Concord, N.C. (loc. 25, pl. 4) was split into two parts (56–OT–11 and 56–OT–11a, tables 7 and 8), and apparent lead-alpha ages of 305 and 540 my were determined for the splits. Analytical errors due to very low lead content and radioactivity apparently render these two analyses useless for dating the syenite. Other zircon from syenite in Cabarrus County, N.C. (loc. 23, pl. 4), has an apparent lead-alpha age that is out of harmony with observed field relations. The sample (HB–39–59, tables 7 and 8) came from a dike that intrudes gneissic granodiorite and massive granite which contain zircon that has apparent lead-alpha ages of 490 and 410 my. Zircon from the syenite dike has an apparent lead-alpha age of 450 my.

Large zircon crystals from a syenite pegmatite dike (USNM 80114 and 60–OT–1000, tables 7 and 8) at the Jones Mine near Zirconia, N.C. (loc. 2, pl. 4) have apparent lead-alpha ages of 280 and 300 my (tables 7 and 8). The syenite pegmatite dike is rich in vermiculite. It occurs in a large septum of sillimanite-mica gneiss in biotite granite gneiss in the Inner Piedmont belt (Olson, 1952, p. 17–22) and is apparently the youngest rock in the exposure. From the descriptions of the Jones Mine, the pegmatite seems to us to be a differentiate from the late syenite dikes that are related to gabbro, norite, and pyroxenite which are particularly common in the Charlotte belt. We think that the apparent lead-alpha age of the zircon crystals is the age of original crystallization of the syenite pegmatite.

Similar large zircon crystals from pegmatite associated with vermiculite 4 miles east of Tigerville, S.C. (loc. 1, pl. 4), have apparent lead-alpha ages of 255, 270, and 260 my (USNM 105674, 60–OT–1001, and 60–OT–1002, tables 7 and 8). We think that this pegmatite is a differentiate of the late syenite dikes and that the apparent age of the zircon is the age of crystallization of the pegmatite.

Field relations show that the bodies of syenite are intruded only by related lamprophyre dikes and by diabase dikes of Late Triassic(?) age. The syenite is not intruded by the youngest granite plutons; hence, it may be slightly younger than the latest granite. The syenite is here interpreted to be Permian in age (table 6). It is the youngest pre-Triassic intrusive rock in South Carolina.

GEOLOGIC SUMMARY

The Carolina slate belt, the Charlotte belt, the Kings Mountain belt, and the Inner Piedmont belt do not differ greatly from each other in the kinds of sedimentary rocks originally formed in them. The same general kinds of sedimentary rocks formed across the whole area: they consisted of shale; siltstone; graywacke; felsic tuffaceous shale, tuffs, and flows; mafic tuffaceous shale, tuffs, and flows; and sparse interbedded conglomerate, sandstone, and limestone. There is no direct evidence to indicate the age of the initial sedimentation, but the presence of granite having an apparent minimum age of Early Cambrian in metamorphosed equivalents of the sedimentary rocks in Anderson and Abbeville Counties suggests that deposition probably began in Precambrian time. A post-Cambrian unconformity is overlain by sedimentary rocks that were subsequently intruded by granites apparently ranging in age from Ordovician to Devonian. Therefore, sediments of Ordovician, Silurian, or Devonian age must have been deposited, but direct evidence for the time of deposition in South Carolina has not been found. A later unconformity appears to have been formed in Devonian or Mississippian time, as the older rocks are overlain by sedimentary rocks of Carboniferous age. These younger rocks were intruded by granite plutons and by dikes of gabbro and syenite of Permian age. Small remnants of sandstone and shale of Late Triassic age lie upon eroded and faulted Paleozoic metasedimentary rocks.

Unconsolidated sediments of late Cretaceous to Recent age cover the older rocks in the eastern part of the State, and alluvial deposits of Quaternary age occupy valleys throughout the State.

Four definable episodes of regional deformation and metamorphism affected the area. Local contact metamorphism seems to have been associated with each episode of regional matamorphism. Superposition of the episodes made polymetamorphic rocks out of all except the youngest marble, phyllite, granite, gabbro, and syenite. The strongest regional metamorphic episode in the Piedmont of South Carolina appears to have been in the Ordovician. It brought parts of the Inner Piedmont belt to the sillimanite-almandine subfacies of the amphibolite facies; the Charlotte belt was in part brought to the albite-epidote-amphibolite facies; and the older rocks of the slate belt were brought, at least locally, to the greenschist facies. A later regional metamorphism seems to be Carboniferious to Permian in age. It is recognizable in the Inner Piedmont belt chiefly as an episode of fracture deformation and cross folding in which transgressive granites were emplaced, accompanied by retrogressive effects such as widespread replacement of sillimanite by white mica, reduction of amphiboles to biotite and chlorite, the extensive recrystallization of biotite, and the alteration of feldspar to muscovite. In the Kings Mountain belt the episode of Carboniferous to Permian age metamorphosed the youngest sedimentary rocks and was accompanied by folding, fracturing, intrusion of crosscutting granites, and the upgrading of earlier formed minerals along the granite contacts. Relations in the slate belt are complex; and local factors, like granite contacts, appear to have exerted control over the metamorphic effects. In areas where the slates were already metamorphosed, the later episode of metamorphism produced some retrogressive effects, such as the conversion of chloritoid to biotite and sericite (Stromquist and Conley, 1959, p. 9). Where the initial regional metamorphism had not affected the slate belt rocks or where the slate belt rocks are younger than the first regional metamorphic episode, the second episode locally raised the rocks to the greenschist facies.

The last episode of metamorphism and igneous intrusion closed with extensive strike-slip faulting and mylonitization in the Brevard belt.

One of the most probable effects of the episodes of regional metamorphism was the expulsion of water and mobile ions from the highly compressed plutonic rocks. The water and mobile ions were forced upward or outward through zones equivalent to what we now recognize as the less plutonic parts of the Inner Piedmont, Kings Mountain, Charlotte, and Carolina slate belts. The escape of these substances partly accounts for the metamorophism undergone by the less plutonic belts. It may also account for some of the metallic and nonmetallic mineral deposits.

Granites of possible Cambrian, Ordovician, Devonian, and Permian age intrude the metasedimentary rocks. Mafic igneous rocks appear to have been intruded about as often in geologic time in South Carolina as have felsic rocks. The last igneous events known in South Carolina are the emplacement of gabbro, peridotite, and syenite in Permian time and the intrusion of diabase dikes in Late Triassic(?) time. Local beds of bentonite of Eocene and Miocene age are found in the sedimentary rocks in the Coastal Plain of South Carolina, and they contain sharply terminated euhedral crystals of zircon of probable pyroclastic origin. No sources for this zircon are yet known in the Piedmont of South Carolina.

Local contact metamorphism marginal to granite plutons has made a variety of small changes in the different belts. In the Inner Piedmont belt there seems to be some reduction in the abundance of garnet in the gneisses around late granites. Intense tourmalinization is common and of many ages. Strong rise in metamorphic grade adjacent to the late granites is common in the Kings Mountain belt but uncommon in the Carolina slate belt. Indeed, contact-metamorphic effects in slate belt rocks around circular plutons are barely evident; where the same pluton cuts across Charlotte belt gneiss, it creates perceptible retrogressive metamorphism.

The shapes of granite plutons tend to differ from belt to belt. Circular granite plutons are generally close to the boundary of or in the Carolina slate belt. Most of the crosscutting granites are in the Charlotte and Kings Mountain belts. Sheetlike, generally conformable, folded masses of granite are most common in the Inner Piedmont belt.

The forms of young unmetamorphosed gabbro, pyroxenite, and syenite masses show no correlation to the belts in which the rocks crystallized. Regardless of the belt, the largest gabbro masses appear to be almost circular in plan. If they are circular in plan in every belt, then they must be pipelike or columnlike in shape and extend without change in shape to great depth. Within a given body there is generally considerable range in grain size of the minerals. Even a thin stringer of pyroxenite in a joint in gabbro in the Carolina slate belt may have crystals of pyroxene several inches across. Therefore, there is no apparent relation between the coarseness of the mafic rock and the belt in which it occurs. There is a gross regional variation in composition of the dikes, but ultramafic phases such as dunite generally are present in the Blue Ridge belt. The gabbro dikes, like the Triassic diabase dikes and the possible feeder dikes for some of the volcanic rocks of the slate belt, are the only igneous rocks that maintain their individual shape and identity through a great thickness of the crust.

SUGGESTIONS FOR FIELDWORK

A very small part of the area underlain by crystalline rocks in South Carolina has been mapped by means of geological methods. Before stratigraphic sequences, structural interpretations, and explanations for the distribution of ore deposits can be established on a firm basis in the State, more geological fieldwork and mapping are necessary.

The inferred stratigraphic sequences and the regional interpretations that we have made, largely with the geologic map of South Carolina (Overstreet and Bell, 1965) as a guide, show that knowledge of the stratigraphy of the Carolina slate belt is the key to the understanding of the stratigraphy and structure throughout the Piedmont. Some areas where study of the slate belt and of the relation of the slate belt to the Kings Mountain belt would be most rewarding are:

1. Kershaw County between Camden and White Oak Creek, and Saluda County at Kempsons Ferry Bridge.
2. Fairfield, Chester, York, Cherokee, and Union Counties in the north, and McCormick County in the south, particularly in parts of the old Elberton (1890) and Crawfordville (1904), 30-minute quadrangles, South Carolina and Georgia, where the relations between the Carolina slate belt and Kings Mountain belt might be most easily established.

Relations between the sequences of sedimentary rocks and the zones of regional metamorphism need particular attention. Places where these relations could be studied to advantage are:

1. Parts of Fairfield, Chester, York, Cherokee, Union, McCormick, and Edgefield Counties where methods of trend-surface analysis applied to large areas of granitoid rocks of the Charlotte belt might show relict bedding.
2. Laurens County where regional metamorphism is apparently athwart the regional trend of bedding in the Kings Mountain belt.
3. Eastern York and northern Lancaster Counties where there is considerable variation in metamorphic grade of the rocks in the slate belt.
4. Cherokee County between the Broad and Pacolet Rivers where there seems to be an abrupt rise in metamorphic grade associated with granitic intrusive rocks.

5. Central and southern Edgefield County where the metamorphic grade varies abruptly.
6. Oconee and Pickens Counties where the hornblende gneiss and marble along the west side of the Inner Piedmont belt might be correlated with similar rocks along the east side of the belt in Laurens County.
7. Oconee and Pickens Counties where effects of regional metamorphism on the Henderson Gneiss need to be studied.
8. Abbeville County where there appears to be a relation between rocks of the greenschist facies and sillimanite-almandine subfacies along the northwestern side of the Kings Mountain belt.

Age determinations of minerals from the Piedmont show that intrusive rocks range in age from Precambrian to Triassic. Bentonite and other rocks indicative of volcanic activity have been noted in coastal-plain sedimentary rocks of post-Cretaceous age. Additional age determinations from felsic volcanic rocks and from intrusive igneous rocks may help to relate the sedimentary sequence in the Piedmont to the geologic time scale and may reveal igneous rocks younger than the Triassic.

Study of the size distribution of prismatic zircon grains in the bentonite deposits in Orangeburg and Calhoun Counties might disclose the direction from which the zircon came and identify the source areas of the volcanic activity as centered in seamounts or on the hinterland.

High-angle faults such as border the Jonesboro basin of Triassic age in North Carolina occur in Chesterfield County and under parts of the coastal plain in South Carolina. Faults of this sort probably cut crystalline rocks in the Piedmont where Triassic sedimentary rocks no longer occur. High-angle faults along the east side of Triassic basins may pass along strike and downdip into low-angle overthrust faults at great depth. High-angle faults on the west side of Triassic basins similarly may pass at great depth into low-angle underthrust faults. Such faults or systems of faults are probably regional in size and can probably be traced from Triassic basins in North Carolina across the crystalline rocks of South Carolina and Georgia. The great fault along the southeastern side of the slate belt in Lexington, Saluda, Edgefield, and McCormick Counties probably belongs to this group of faults of Triassic age. Other places where similar faults may be found are:

1. Between Tradesville, Lancaster County, and Fort Lawn, Chester County.
2. Along the northern edge of the slate belt in Newberry and Fairfield Counties.
3. In Edgefield County at the State line just north of Aiken County.

Possibly renewed movement took place in Eocene or later time along faults formed in Late Triassic time (E. F. Overstreet, oral commun., 1961). Two complementary directions of probable movement exist: motion on east-northeast-trending faults and motion on north-northwest-trending diabase-bearing faults. Possible evidence for these movements is shown by geologic maps of Georgia. An east-northeast-trending fault having small downward displacement on the north side was shown by MacNeil (1947) to cut sedimentary rocks of Eocene age in Dooley County, Ga. Possible evidence for renewed movement on buried north-northwest-trending faults is the abrupt change in sedimentary formations on opposite sides of the Flint River in Macon County, Ga. (Cooke, 1943, pl. 1). The course of the river and the strike of the contacts is similar to the trend of diabase dikes in adjacent parts of the Piedmont (Stose and Smith, 1939, map). Areas in the Atlantic Coastal Plain of South Carolina where evidence might be sought for renewed movement on faults formed in Triassic time are:

1. On the east-northeast line in Lexington County west-southwest of Lexington.
2. On the west-northwest line in Kershaw and Lancaster Counties.

Relations inferred for the Brevard belt show that it is a regional structure, but details about its character in South Carolina are largely unknown. Oconee County is a favorable place to study the belt, particularly the limestones.

The data shown on the large geologic map (Overstreet and Bell, 1965) have been interpreted by us as indicating that rocks exposed in the Piedmont were formed under many different combinations of pressure and temperature ranging from the environments of high-grade gneiss and plutonic igneous rocks to slightly metamorphosed argillite and tuff pierced by shallow bodies of granite. The geologic environment seems much more diverse than was formerly thought. The idea that the Piedmont consists only of the so-called deep and barren roots of ancient mountain systems is untenable. New interpretations of the structure in the Piedmont suggested by the geologic map indicate that industrial minerals and ores heretofore unknown or recognized only as mineralogical curiosities may exist in exploitable abundance. Structures that are worth careful study for possible relation to ore deposits are:

1. The remarkable circular felsic plutons in the Carolina slate belt and in the Charlotte belt and possibly similar unbreached plutons that may exist in the slate belt.
2. The oval or kidney-shaped masses of gabbro, pyroxenite, norite, and syenite.

3. The gold-bearing quartz veins that cut sedimentary rocks of Late Triassic age and are offset by Late Triassic(?) diabase dikes in Chesterfield County (Lieber, 1858a, p. 52); these veins may offer an insight into the possible age of late-stage gold mineralization.

Data on plate 3 and the large geologic map (Overstreet and Bell, 1965) suggest a regional zoning of mineral deposits in South Carolina. Sheet muscovite and sillimanite are found in the belts of high-rank metamorphic rocks. Gold occurs most abundantly in the low-rank rocks. We think that the geologic belts and the sedimentary sequences and igneous episodes suggested by the geologic map can be used as guides to the regional zoning of mineral deposits and can aid in the search for minerals characteristically found in specific pressure-temperature associations and sedimentary or igneous environments.

New methods of studying the regional zoning of industrial minerals and elements in the Piedmont of South Carolina are needed to compensate for the lack of surface expression of ore deposits in this deeply weathered area. A useful field procedure for the study of regional zoning of minerals and elements in weathered areas is combined heavy-mineral and geochemical reconnaissance such as we have done in parts of North and South Carolina (Bell and Overstreet, 1960, map; Overstreet and Bell, 1960b, map; Overstreet and Griffitts, 1955, map). Results of heavy-mineral and geochemical exploration compared with the provisional geologic map should offer a new basis for prospecting.

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