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A. S. FURCRON, Director

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ATLANTA

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LETTER OF TRANSMITTAL

September 1, 1968

His Excellency, Lester G. Maddox
Governor of Georgia and
Commissioner Ex-Officio
State Division of Conservation
Atlanta, Georgia

Dear Governor Maddox:

I have the honor to submit herewith Bulletin 80 of the Department of Mines, Mining and Geology entitled, "Paleozoic-Precambrian Appalachian Problems."

This report contains a number of articles prepared by Georgia geologists and by some geologists working outside of the State upon problems relating to Georgia's oldest rocks. These problems are of mutual interest to adjoining and neighboring states. Articles in this report bear upon investigations which have been debatable to a considerable extent, and it is believed that these papers will materially assist in the preparation of new geologic maps which are planned for the State. Basically, the papers suggest new approaches upon the structure, stratigraphy, and lithologic aspects of these ancient rocks.

Very respectfully yours,

A. S. Furcron

A. S. Furcron
Director

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STRATIGRAPHY OF THE CHICKAMAUGA SUPERGROUP IN ITS TYPE AREA

By

Robert C. Milici

Tennessee Division of Geology

Knoxville, Tennessee 37919

and

James W. Smith

Georgia Department of Mines, Mining and Geology

Atlanta, Georgia 30334

In cooperation with the

Tennessee Division of Geology

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ABSTRACT

The Chickamauga Limestone in its type area includes all strata from the top of the Knox Group to the base of the Upper Ordovician. In its type area the Chickamauga is composed of about 1450 feet of limestone and argillaceous limestone in formations of the Stones River and Nashville Groups. The Chickamauga is herein considered a Supergroup. The Chickamauga Supergroup overlies the Knox above a well-developed unconformity, and consists in ascending order of the following formations: Pond Spring Formation, Murfreesboro Limestone, Ridley Limestone, Lebanon Limestone, and Carters Limestone of the Stones River Group; and Hermitage Formation, Cannon Limestone, and Catheys Formation of the Nashville Group. The Catheys is overlain unconformably by the Sequatchie Formation in the valley of West Chickamauga Creek, and conformably by the Inman Formation in Lookout Valley.

INTRODUCTION

Regional Geologic Setting

Recent studies by the Tennessee Division of Geology have shown that Middle and Upper Ordovician rock units of the Central Basin and Sequatchie Valley extend eastward into the Valley and Ridge province of southeastern Tennessee and northwestern Georgia.

The present study, a cooperative project between the Georgia Department of Mines, Mining and Geology and the Tennessee Division of Geology, was undertaken to establish in more detail the stratigraphy of the Chickamauga Limestone of earlier usage in the type area, and thus to provide a common basis for continued stratigraphic studies in both states.

Correlation of Middle and Upper Ordovician strata of northwestern Georgia with the Central Basin and the Sequatchie Valley region is based primarily on detailed regional studies by Wilson (1949) and Milici (in preparation) and on many geologic quadrangles published by the Tennessee Division of Geology.

Many detailed measured sections of Middle Ordovician strata in Sequatchie Valley and selected mapped areas in the southwestern part of the Tennessee Valley and Ridge support the correlation. The studies in Tennessee have not yet been published.

The present study is confined to Ordovician strata in the northwestern corner of Georgia. The region is folded and broken by faults of only small displacement, and, except for the Sequatchie Valley Fault, is structurally continuous with Central Tennessee. Three major anticlines arch Ordovician limestones to the surface in the region—the McLemore Cove, Wills Creek, and Lookout Valley anticlines. The Pigeon Mountain syncline bounds the McLemore anticline on the east, and the Lookout Mountain syncline separates the McLemore, Wills Creek, and Lookout Valley anticlines (fig. 1).

The oldest strata of the region, those of the Knox Group, are exposed in the core of Wills Creek and McLemore Cove anticlines, where they underlie low but prominent hills and ridges. Missionary Ridge is one of these hills and separates the Chickamauga and Chattanooga Valleys in which much of our study was made. Chickamauga and Chattanooga Valleys merge southwestward and form McLemore Cove on the nose of the McLemore anticline.

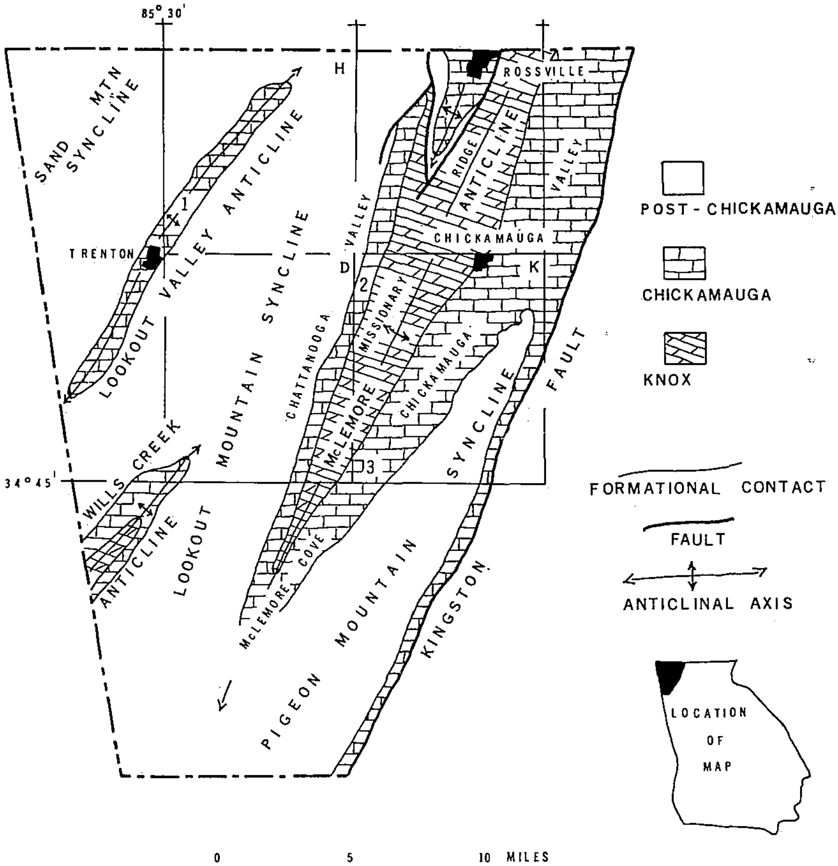

Figure 1—Generalized geologic map of northwestern Georgia, showing distribution of the Chickamauga Supergroup, after Butts and Gildersleeve (1948).

Map Number—1 is the I-59 section. Map Number—2 is the Mill Creek section, and Map Number—3 is the Davis Crossroads section. H is the Hooker quadrangle, D is the Durham quadrangle, K is the Kensington quadrangle.

Previous Investigations

The Chickamauga Limestone was named by Hayes (1891, p. 143) for exposures in the valley of West Chickamauga Creek in the Valley and Ridge Province of northwestern Georgia and adjacent portions of Tennessee. The formation (table 1) included all strata between the top of the Knox Group and the base of the Rockwood Formation(Hayes, 1894). The Rockwood Formation in the Ringgold quadrangle (Hayes, 1894) may have included the Sequatchie Formation, as did the Rockwood Formation of early workers in Tennessee, until Ulrich (1911) defined the Sequatchie.

Spencer (1893) and Maynard (1912) described the Chickamauga of northwestern Georgia in general terms.

Butts and Gildersleeve (1948, p. 19) divided the Chickamauga

GEORGIA					TENNESSEE			GEORGIA	
HAYES (1894)	MAYNARD (1912)	BUTTS AND GILDERSLEEVE (1948)	COOPER (1956)	CRESSLER (1964)	BASSLER (1932)	WILSON (1949)	SWINGLE (1964)	THIS REPORT	
CHICKAMAUGA LIMESTONE	CHICKAMAUGA FORMATION	SEQUATCHIE		SEQUATCHIE	RICHMOND	RICHMOND: SEQUATCHIE	SEQUATCHIE-JUNIATA	SEQUATCHIE	UPPER ORDOVICIAN
		CHICKAMAUGA LIMESTONE: MAYSVILLE		CHICKAMAUGA LIMESTONE: MAYSVILLE	SEQUATCHIE / LEIPERS	MAYSVILLE: LEIPERS	CHICKAMAUGA GROUP	LEIPERS	
						EDEN: INMAN		INMAN	
		TRENTON		TRENTON	TRENTON GROUP: CATHEYS	NASHVILLE GROUP: CATHEYS		CHICKAMAUGA SUPERGROUP: NASHVILLE GROUP: CATHEYS	MIDDLE ORDOVICIAN
					CANNON / BIGBY	BIGBY-CANNON		CANNON	
			TRENTON		HERMITAGE	HERMITAGE		HERMITAGE	
		LOWVILLE	CARTERS	LOWVILLE-MOCCASIN	BLACK RIVER: LOWVILLE; TYRONE / CARTERS	CARTERS		CARTERS	
		LEBANON	LEBANON	LEBANON	STONES RIVER GROUP: LEBANON	STONES RIVER GROUP: LEBANON		STONES RIVER GROUP: LEBANON	
		LENOIR (RIDLEY)	RIDLEY	LENOIR	RIDLEY	RIDLEY		RIDLEY	
			(PIERCE)		PIERCE	PIERCE		(PIERCE)	
		MOSHEIM	MURFREESBORO	MOSHEIM					
		MURFREES-BORO		MURFREES-BORO	MURFREES-BORO	MURFREES-BORO		MURFREES-BORO	
		NEWALA [2]		NEWALA		WELLS CREEK		POND SPRING	
KNOX DOLOMITE	KNOX DOLOMITE	KNOX DOLOMITE		KNOX GROUP	BEEKMANTOWN	KNOX DOLOMITE	KNOX GROUP	KNOX GROUP	LOWER ORDOVICIAN[1]

1 THE KNOX GROUP CONTAINS THE CAMBRIAN COPPER RIDGE DOLOMITE AT BASE

2 DASHED LINE IS THE BASE OF THE NEWALA IN THE CHICKAMAUGA AREA, AND THE TOP OF THE NEWALA NEAR CHATSWORTH

Table 1—Stratigraphic nomenclature of Ordovician strata in Tennessee and northwestern Georgia.

in its type area into the following formations: Newala, Murfreesboro, Mosheim, Lenoir (Ridley), Lebanon, Lowville, Trenton, and Maysville; they included the Murfreesboro, Mosheim, Lenoir (Ridley), and Lebanon within the Stones River Group. The Stones River Group of Butts and Gildersleeve in northwestern Georgia contains the same formations that Bassler (1932) included in the Stones River in Central Tennessee. Butts and Gildersleeve (1948, p. 27 et seq.) and Bassler (1932, p. 48) described the Blount Group (Ulrich, 1911) of the eastern Valley and Ridge as succeeding the Stones River, and they did not recognize that deposits formed in the shelf carbonate environment in Central Tennessee and in the Chickamauga area were deposited at least in part contemporaneously with Middle Ordovician terrigenous sediments in the eastern regions. Hayes (1894) earlier had noted that the Chickamauga "changed in character" between its western and eastern exposures.

Cooper (1956, p. 54-55) described the paleontology and stratigraphy of the Chickamauga in the area of the present study along the road from Pond Spring to Catlett Gap, Kensington quadrangle. He studied strata from the Murfreesboro to the Carters, and disagreed in detail with the correlations Butts and Gildersleeve (1948) made with the Central Tennessee formations and with formations elsewhere in the Valley and Ridge. Butts and Gildersleeve (1948) described Mosheim over Murfreesboro, and correlated the Ridley of northwestern Georgia with the Lenoir of eastern Tennessee. The Mosheim of Butts and Gildersleeve (1948) is a calcilutite at or near the top of the Murfreesboro Limestone. In the central Valley and Ridge of East Tennessee the Mosheim is a calcilutite member of the Lenoir Limestone (Rodgers, 1953, p. 69). Correlation of the Lenoir of Tennessee with the Ridley of northwestern Georgia by Butts and Gildersleeve (1948) was based on *Maclurites*. Cooper (1956, p. 55) showed that this correlation was incorrect and assigned the Mosheim and *Maclurites* beds of Butts and Gildersleeve to the Murfreesboro Limestone in the Chickamauga area. The present work is in agreement with the correlations of Cooper.

Rodgers (1953) and Allen and Lester (1957) described in some detail the lateral gradation of carbonate strata into terrigenous strata, thus correcting a misconception of some earlier workers.

Allen and Lester (1954) described the fossils of northwestern Georgia and later (1957) divided Middle and Upper Ordovician strata there into zones. However, they made no attempt to define the Chickamauga Limestone as a formal unit.

In East Tennessee Swingle (1964) considered the Chickamauga a Group and included therein all strata between the top of the Knox Group and the base of the Sequatchie or Juniata. This usage was followed in the *Geologic Map of Tennessee* that was subsequently published (Hardeman, Miller, and Swingle, 1966).

Cressler (1964) included all strata between the base of the Newala and the top of the Sequatchie in the Chickamauga Limestone in Walker County, Georgia. In northwestern Georgia Butts and Gildersleeve recognized Maysville as a formation only in Taylor Ridge (1948, p. 33) and there included it in the Chickamauga. Cressler (1964) included both Maysville and Sequatchie in the Chickamauga, although Butts and Gildersleeve (1948) mapped the Sequatchie with Red Mountain (Silurian).

Croft (1964) included all strata between the top of the Knox Dolomite and the base of the Sequatchie Formation in the Chickamauga Limestone in Dade County, Georgia. There, Croft (p. 8) divided the Chickamauga into an upper limestone member and a lower limestone and dolomite member, "... at a thin zone of green chert and bentonite, which is about 20 feet thick. . . ."

The stratigraphy and nomenclature in the Central Basin of Tennessee have been described in detail by Wilson (1949) and are summarized only briefly here. The Stones River and Nashville Groups were named by Safford (1851) for exposures in the Central Basin of Tennessee. Subsequently, these Middle Ordovician groups and their constituent formations were defined and classified differently by workers in different areas (table 1). Wilson (1949, fig. 1, p. 24) defined the Stones River Group as including the Wells Creek Dolomite, Murfreesboro Limestone, Pierce Limestone, Ridley Limestone, Lebanon Limestone and Carters Limestone. He included in the Nashville Group the Hermitage Formation, the Bigby-Cannon Limestone, and the Catheys Formation.

Present Investigation

In the course of this study a detailed geologic map of Chickamauga Valley near the southern edge of the town of Chickamauga was prepared (fig. 2). Reference sections or areas of best exposure were described for formations of the Stones River and Nashville Groups in the mapped area and in places nearby where the strata are well exposed (figs. 1 and 3). The Stones

River and Nashville Groups constitute the Chickamauga Supergroup in its type area. The area mapped was selected because of good exposure of units between the Knox and Sequatchie and is an excellent reference area for the Chickamauga Supergroup. In its type area the Chickamauga ranges from about 1425 to 1475 feet thick.

Supergroup status was selected for the Chickamauga to provide maximum flexibility for future stratigraphic studies. It is anticipated that workers in the future will establish groups elsewhere that reflect different but approximately contemporaneous

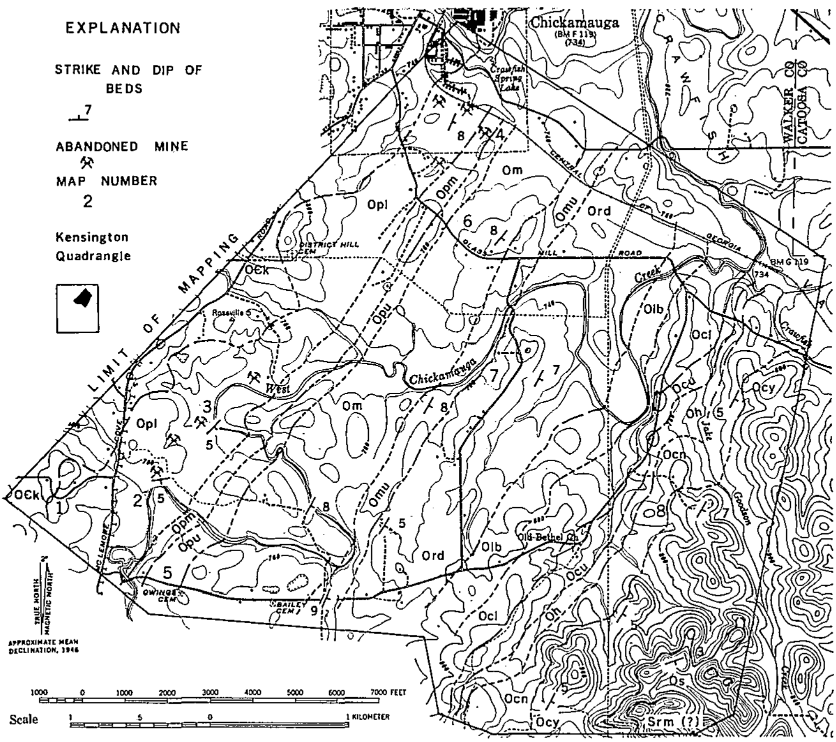

Figure 2—Geologic map of the Chickamauga Supergroup at its type area. Knox Group, undivided—OЄk; Pond Spring Formation, lower member—Opl, middle member—Opm, upper member—Opu; Murfreesboro Limestone—Om, upper member—Omu; Ridley Limestone—Or; Lebanon Limestone—Olb; Carters Limestone, lower member—Ocl, upper member—Ocu; Hermitage Formation —Oh; Cannon Limestone—Ocn; Cathey s Formation—Ocy; Sequatchie Formation—Os; basal Red Mountain Formation(?)—Srm(?). Observed formational contacts are solid lines, long dashed where approximately located, short dashed where projected. Base from USGS-TVA Kensington Quadrangle, Georgia; contour interval is 20 feet.

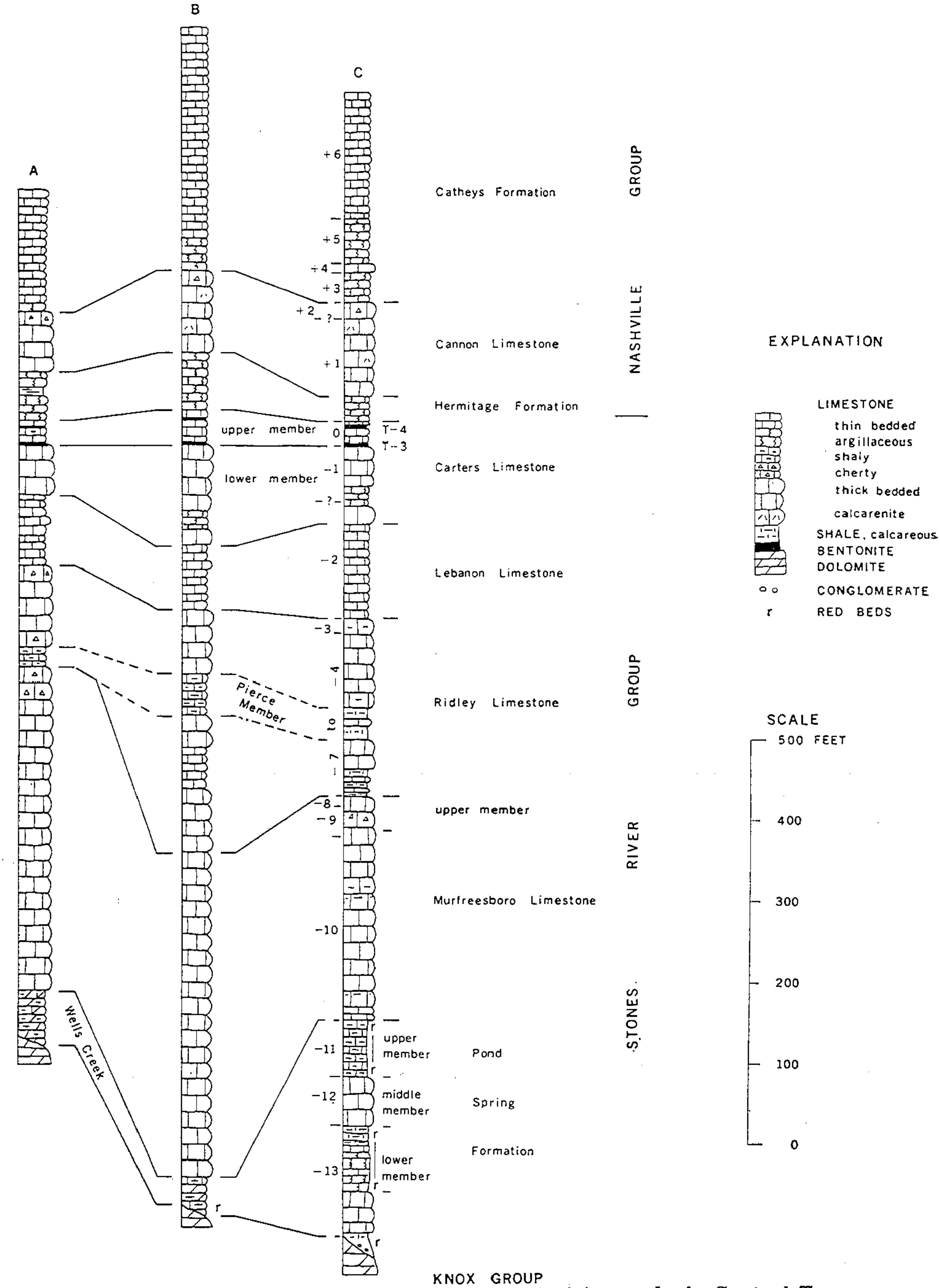

Figure 3—Columnar sections of Middle Ordovician rocks in Central Tennessee (A), Sequatchie Valley (B), and the Chickamauga area (C). The zones, offshore facies, of Allen and Lester (1957) are shown at the left margin of column C.

local sedimentary conditions. The names Stones River and Nashville may be applicable to Middle Ordovician shelf carbonate units established by Miller and Brosge (1954) in southwestern Virginia and mapped in the northwestern part of the Tennessee Valley and Ridge Province (for example, see Harris, 1965). If Stones River and Nashville cannot be extended further even in the shelf carbonate facies, new group names could be defined and correlated with established group sequences. Furthermore, such sequences as Lenoir-Athens-Holston-Tellico-Ottosee in the southeastern part of the Tennessee Valley and Ridge may constitute one or more groups (near shore facies of Allen and Lester, 1957), and the Lenoir-Sevier sequence may be a separate group in northeastern Tennessee. Group sequences thus defined would be useful in showing regional facies variations on maps of regional scale.

The classification of Wilson (1949) is used by the present writers with minor exception. The Pierce Limestone is a mappable unit in the Central Basin of Tennessee and in parts of Sequatchie Valley. In Sequatchie Valley (Tennessee) and northwestern Georgia, Ridley-type fucoidal limestones are above and below Pierce equivalents, and the Pierce is considered a member of the Ridley. Also, in northwestern Georgia the Richmond Group of Wilson (1949) is represented by the Sequatchie Formation. Fernvale-type variegated recrystallized limestones occur within the Sequatchie Formation in Lookout Valley, but precise correlations have not been demonstrated.

The Carters Limestone (this report) is equivalent to the Lowville of Butts and Gildersleeve and perhaps the upper part of the Lebanon of Butts and Gildersleeve (1948).

Age of the Chickamauga Supergroup

The Chickamauga Supergroup in the Chickamauga area includes all strata between the top of the Knox Group, which is marked regionally by an unconformity, and the base of Upper Ordovician red beds.

In Lookout Valley, where Inman (Eden) red beds are below Leipers (Maysville), Butts and Gildersleeve (1948) apparently included both formations in the Sequatchie. Similarly, Ulrich and Butts (cf. Burchard, 1913, p. 31-41) restricted the Sequatchie Formation to red beds above the Leipers in the Valley and Ridge of East Tennessee, but included Inman red beds and the Leipers in the Sequatchie Formation in the Sequatchie Valley and Chattanooga areas (Milici, in preparation).

In McLemore Cove near the town of Chickamauga, the Sequatchie overlies the Catheys unconformably and the Inman and Leipers are absent. Thus in its type area Butts and Gildersleeve (1948) excluded Upper Ordovician strata from the Chickamauga either by accident or design, and the youngest Chickamauga is Middle Ordovician.

The sequence Knox-Chickamauga-"Sequatchie" in the Chickamauga type area is the same as Knox-Stones River-Nashville-Inman-Leipers-Sequatchie in Sequatchie Valley.

The age of the oldest Chickamauga strata in the type area is questionable. Butts and Gildersleeve (1948) mapped Newala above the post-Knox unconformity in Chickamauga Valley. They noted *Ceratopea* in abundance within the formation and correlated the strata there with the upper Beekmantown (Kingsport-Mascot) of Tennessee and Virginia and the Cotter and Powell Limestones of Arkansas (1948, p. 21). If the geologic map and descriptions of Butts and Gildersleeve are accurate then the Chickamauga in some places contains Lower Ordovician beds. The geologic maps made by Butts and Gildersleeve (1948) and the writers are sufficiently similar to indicate that the specimens of *Ceratopea* described by them near Chickamauga are above the post-Knox unconformity (1948, p. 21-22).

Acknowledgments

The manuscript was critically reviewed and edited by L. D. Harris, R. A. Laurence, C. W. Wilson, Jr., L. Alberstadt, R. J. Floyd, E. T. Luther, and S. W. Maher.

STONES RIVER GROUP

The Newala Problem

The Newala Limestone was named by Butts (1928, p. 95) for exposures near Newala Station, Shelby County, Alabama. In its type area Butts described the formation as thick-bedded, fine-grained gray limestone and coarse-grained dolomite. There the Newala is beneath the Odenville Limestone, apparently is below the post-Knox unconformity (Butts, 1928, p. 95-104), and thus is part of the Knox Group.

In northwestern Georgia Butts and Gildersleeve (1948, p. 19) described the Newala as "a rather thick-bedded, pure, blue limestone. . . . The formation is massive, thick, or moderately thick-bedded. Blue-gray, finely crystalline, and some compact dove layers (vaughanite) occur."

Butts and Gildersleeve (1948) described only one lithologic type of the very complex formation, and did not recognize the basal dolomite and chert-pebble conglomerates and the extensive development of red shales, variegated dolomitic limestones, and "red-mottled" limestone that occur within the formation in the Chickamauga area. They recognized "red or red-mottled limestone interbedded with blue or dove beds" in eastern belts but included these (erroneously ?) within the Murfreesboro Limestone (1948, p. 22-23).

It has been known for many years that the Knox-Chickamauga boundary is marked by a regional unconformity that in places preserves considerable topographic relief on the ancient Knox erosion surface (for example, see Maynard, 1912, p. 95, 96; Born and Burwell, 1939, p. 28; Bentall and Collins, 1945; Rodgers, 1953, p. 69-70; Bridge, 1955; Harris, 1960; Wedow, 1961). Lowermost Chickamauga rests on different formations of the Knox Group in different places (Butts, 1928, p. 120-121; Butts and Gildersleeve, 1948, p. 18; Bridge, 1955). The unconformity is overlain in places by large amounts of conglomerates and sedimentary breccias. Bridge (1955) described one of the more spectacular of these in Tennessee, which he named the Douglas Lake Member of the Lenoir Limestone. Equally spectacular is the Attalla Conglomerate in Alabama, described by Butts (1928, p. 120-121).

The Newala of Butts and Gildersleeve (1948) is above the post-Knox unconformity in the Chickamauga area. Munyan, however, has shown that the Newala of Butts and Gildersleeve is below the post-Knox unconformity near Chatsworth, Georgia, and is there within the Knox Group (1951, p. 52-53). Butts and Gildersleeve thus appear to have either misidentified the Newala or to have mislocated the formation on their map in the Chickamauga area.

The "Newala" in the Chickamauga area is in the same stratigraphic position as the Wells Creek Dolomite of Lusk (1927) and Bentall and Collins (1945). The name Wells Creek is no longer used by the Tennessee Division of Geology because of misidentification at its type locality. Accordingly, the writers consider it improper to extend the name Wells Creek into Georgia and instead propose that the strata in the Chickamauga area between the top of the Knox Group and the base of the Murfreesboro Limestone be named the Pond Spring Formation. The name is taken from the town of Pond Spring, which is 1 mile southwest of Map Number 1, figure 2. The type section of the formation is a composite and is at Map Numbers 1, 2, 3, 4, and 5 (fig. 2).

The Pond Spring Formation is in the same stratigraphic position as the Wells Creek Dolomite of Bentall and Collins (1945), and by analogy to the classification of Wilson (1949) the Pond Spring is hereby included within the Stones River Group of northwestern Georgia.

The Pond Spring Formation in part contains strata called the Long Savannah Formation by Cooper (1956, p. 75-76), named from exposures in the Snow Hill quadrangle, Tennessee.

Pond Spring Formation

The Pond Spring Formation overlies the Knox Group unconformably and is overlain by the Murfreesboro Limestone. The basal conglomerate and red beds of the Chickamauga in the area mapped by the writers are consistently about 1000 feet east of the contact selected by Cressler (1964). The Newala of Cressler includes "much dolomite in lower part," and contains in the Chickamauga area some strata that Butts and Gildersleeve (1948) and the present writers mapped as Knox.

In the Chickamauga area the Pond Spring Formation is 250 to 300 feet thick and divisible into three members, which are herein called the lower, middle, and upper members. The lower member is best exposed on both sides of Ketner Branch and 2000 feet northeast of the Ketner Branch-West Chickamauga Creek confluence, along the southwestern bank of West Chickamauga Creek (fig. 2, Map Numbers—1, 2, 3). The middle member is almost completely exposed in the Chickamauga quarry (fig. 2, Map Number—4). The upper member is best exposed, although badly weathered, in roadcuts along Old Bethel Church road near Owings Cemetery (fig. 2, Map Number—5), and in the Chickamauga quarry where the lower 6 feet is exposed.

The lower member of the Pond Spring Formation ranges from about 140 to 170 feet in thickness. In the mapped area the member is thickest in the Ketner Branch sections and thinnest at the southern limits of the town of Chickamauga. The lower member overlies the Knox unconformably and may be subdivided further in some places into a lower conglomerate-red bed sequence, about 20 to 25 feet thick; a middle calcilutite, about 50 feet thick; and an upper red bed unit about 60 to 85 feet thick. The sequence of the lower member thus reflects the order of deposition of the entire formation.

The basal conglomerate of the lower member is commonly 1 to 2 feet thick in the Chickamauga area and consists of rounded light-gray, sugary, fine-grained dolomite pebbles and boulders as large as 1 foot across in a matrix of porous, light-gray or light greenish-gray dolosiltite. Both matrix and conglomerate were derived from disintegration of the underlying Knox. In places dolosiltite matrix material fills joints and irregular open spaces in upper Knox beds below the unconformity. The dolosiltite matrix material extends about 10 feet above the basal conglomerate and is overlain by 10 or 15 feet of mottled grayish-red and greenish-gray calcisiltites. Thicknesses range widely because of topography developed on the ancient Knox erosion surface, and in this area the material in the conglomerate reflects the local character of the underlying Knox.

The middle calcilutite of the lower member is thick-bedded, light-gray limestone that is typical of the Mosheim member of the Lenoir Limestone in Tennessee. In places the calcilutite contains a few interbeds of porous, light greenish-gray calcisiltite similar to the porous dolosiltite matrix rock just above the unconformity. The lower red beds thin northeastward from Ketner Branch and appear to be absent at Chickamauga, where the middle calcilutite is on or near the top of the Knox.

Upper red beds of the lower member are calcisiltites, calcilutites, and mudstones similar to, but not as argillaceous as, the lower red beds. Greenish-gray and mottled greenish-gray and grayish-red limestones are well developed and have been quarried extensively for building stone. The building stone has been used locally as a veneer on the exterior of houses. The best rock for this purpose is 15 to 25 feet above the Mosheim-type calcilutite. A few gray calcilutites are interbedded with the mottled red beds, but these are generally less than 10 feet thick. The upper red beds also thin northward from Ketner Branch sections, where they are about 85 feet thick, to about 60 feet at Chickamauga.

Fossils are generally absent in the lower member of the Pond Spring Formation.

The middle member of the Pond Spring Formation is composed of about 60 feet of generally thick-bedded gray calcilutite and calcisiltite. Some beds are argillaceous and are light-olive gray. Fossils are generally lacking, although several beds are fossil-fragmental.

The contact of the lower and middle members is apparently conformable and is at the base of the first gray limestone above mottled greenish-gray, grayish-red and gray limestones. The greenish-gray and grayish-red colors of mottled rock of the lower member are progressively more subdued upward, and are only poorly expressed in the upper beds of the member. The contact between the lower and middle members is exposed in the Chickamauga quarry (fig. 2, Map Number—4).

The contact between the middle and upper members also is exposed in the Chickamauga quarry and is above argillaceous medium-gray or yellowish-gray calcilutites and below greenish-gray and grayish-red mottled argillaceous calcisiltites. The upper and lower members weather more readily than the middle member, which contains much less argillaceous material, and as a result the middle member is comparatively well exposed.

The upper member of the Pond Spring Formation consists of about 70 feet of argillaceous calcisiltites that weather to calcareous mudstones and shales. Some of the rock is mottled grayish-red, pale-red and moderate yellowish-green. Bedding is generally ¼ inch to 6 inches thick. Thinner beds are even and have regular surfaces; thicker beds weather rounded.

The Pond Spring Formation is equivalent to zones –13 through –11 of Allen and Lester (1957) in the valley of West Chickamauga Creek.

Murfreesboro Limestone

The Murfreesboro Limestone was named by Safford and Killebrew (1900, p. 125) for exposures in and around Murfreesboro, Rutherford County, Tennessee. In northwestern Georgia the Murfreesboro Limestone overlies the Pond Spring Formation with apparent conformity and the basal Murfreesboro contact is mapped above red-mottled shales, limestones, or dolomitic limestones.

The Murfreesboro Limestone is best exposed in fields north of Glass Mill Road, between the road and the Chickamauga quarry (fig. 2, Map Number—6); along Old Bethel Church road between Owings Cemetery and Bailey Cemetery; along West Chickamauga Creek about 1500 feet north of the road; and along Mill Creek in Chattanooga Valley, between the Tennessee, Alabama, and Georgia Railroad and Chattanooga Creek (fig. 4). No one section is exposed completely, and the character of the formation was determined from study of the several sections.

The formation is about 275 feet thick and is composed predominantly of medium-dark gray to dark-gray calcilutite and calcisiltite. Light-gray and olive-gray limestones are common, and greenish-gray calcareous shales and shaly limestones are interbedded with the limestones.

The limestones are generally even textured and in beds 6 inches to 1 foot thick. Some beds ¼ to ½ inch thick occur in the lower part of the formation; and basal beds are laminated, very thin-bedded, and even-bedded argillaceous limestones that weather to calcareous shale. The Murfreesboro-Pond Spring contact and the basal laminated beds of the Murfreesboro are best exposed along West Chickamauga Creek 1500 feet northeast of Owings Cemetery.

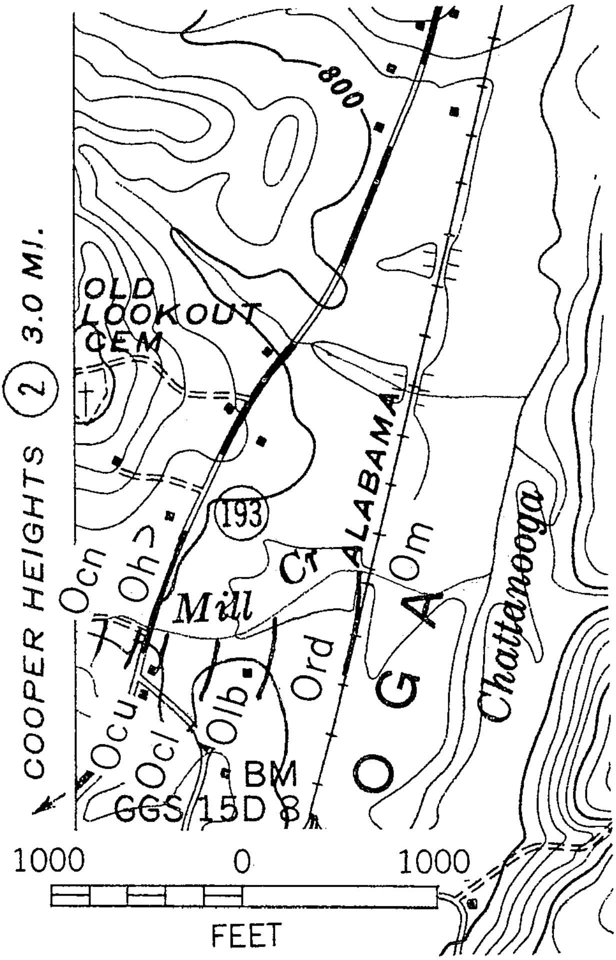

Figure 4—*Geologic contacts at the Mill Creek Section, Chattanooga Valley, Kensington quadrangle (fig. 1, Map Number—2). Murfreesboro Limestone—Om; Ridley Limestone—Ord; Lebanon Limestone—Olb; Carters Limestone, lower member—Ocl, upper member—Ocu; Hermitage Formation—Oh; Cannon Limestone—Ocn. Base from USGS-TVA Kensington Quadrangle; contour interval 20 feet.*

The bedding of Murfreesboro Limestone is generally even, and some beds have regular surfaces. Partings or seams of yellowish-gray-weathering argillaceous limestone are common. Some splotchy or fucoidal beds similar to Ridley limestones occur in the Murfreesboro, but these are generally less than 10 feet thick. Light- to medium-light gray calcilutite occurs in some places within the Murfreesboro, and in the Mill Creek section is at the contact between the Murfreesboro and Ridley.

The upper part of the formation contains a zone of ropy brownish-black chert that has been described both by Butts and Gildersleeve (1948, p. 22) and by Allen and Lester (1957, p. 89-91). The chert is in medium-dark gray calcilutite that contains many unevenly bedded seams of argillaceous calcilutite or calcisiltite ½ inch to 2 inches thick, and is in nodules or irregular lenses along and across bedding. Weathered chert in rectangular pieces is found in soil above the chert-bearing strata and is useful in identifying the upper Murfreesboro where only residuum is visible.

The ropy chert-bearing strata are overlain by light- to medium-gray calcilutite that may be in thin or laminated beds or in beds as much as 2 feet thick.

Allen and Lester (1957) described the ropy chert-bearing strata as zone –9 and measured thicknesses of 37 and 47 feet in the valley of West Chickamauga Creek and in Chattanooga Valley. They referred the overlying calcilutite to zone –8 and described it as 12 to 20 feet thick in this area.

The writers have mapped the ropy chert and calcilutite strata as an upper member of the Murfreesboro in the valley of West Chickamauga Creek; the base of the upper member was selected below the lowest beds of argillaceous limestone and above medium-dark gray pure calcilutites. The top of the member is the Murfreesboro-Ridley contact. The upper member of the Murfreesboro is best exposed on the southeast bank of West Chickamauga Creek in the center of the map area (fig. 2, Map Number—7).

Ridley Limestone

The Ridley Limestone was named by Safford (1869, p. 216) for exposures near Ridleys Mill in Rutherford County, Tennessee. The Ridley overlies the Murfreesboro with apparent conformity and the contact is selected above beds of well-bedded light- to medium-gray, laminated or thin- to thick-bedded calcilutite. Ridley-type limestones are "fucoidal" and not as well bedded as Murfreesboro limestones, and in places are in the Murfreesboro. As far as is known Murfreesboro (Mosheim)-type calcilutites do not occur within the Ridley.

The Ridley Limestone is well exposed in fields south of Mill Creek, Chattanooga Valley, and in the mapped area (fig. 2) of the Kensington quadrangle. There it consists of about 260 feet of limestone and calcareous shale. Limestone ranges from calcilutite to coarse-grained calcarenite in shades of gray to olive-gray. Characteristic Ridley Limestone beds are medium-gray to medium-dark gray calcisiltite or fine-grained calcarenite. The rock contains irregular splotches of coarser-grained more argillaceous or dolomitic "fucoidal" limestone. Wilson (1949, p. 26-29) postulated that the fucoids were formed by selective dolomitization of organic debris during diagenesis of carbonate sediment. Chemical analyses of "sugary" coarser-grained materials show both a higher $MgCO_3$ and insoluble residue content than associated fine-grained rock (Wilson, 1949, p. 27). However, weathered fucoids effervesce in 10 percent HCl in a manner similar to the host rock.

In the Kensington quadrangle the Ridley contains two zones of calcareous shale and mudstone. In the Mill Creek section the lower shale-mudstone is 35 feet thick and is 34 feet above the base of the formation. The upper zone (Pierce Member) is approximately 41 feet thick and is 107 feet above the base of the formation. In Sequatchie Valley, Tennessee, the Ridley contains a prominent shale member (Pierce Member) in the middle or upper half of the formation.

The Ridley Limestone is equivalent to zones –7 through –3, and perhaps the lower part of zone –2 of Allen and Lester (1957) in Chattanooga Valley and in the valley of West Chickamauga Creek.

Lebanon Limestone

The Lebanon Limestone was named by Safford and Killebrew (1900, p. 125-126) for exposures in the vicinity of Lebanon, Wilson County, Tennessee. The Lebanon overlies the Ridley with apparent conformity. The Lebanon Limestone is well exposed in the Mill Creek section, where it is 113 feet thick. The formation consists of medium-gray to medium-dark gray calcilutite to coarse-grained calcarenite, and the rock contains numerous argillaceous or dolomitic fucoids. The Lebanon-Ridley contact is picked where beds as much as 8 inches thick give way to beds generally 1 to 2 inches thick. In addition to being generally thinner bedded than the Ridley, the Lebanon is abundantly fossiliferous and contains numerous brachiopods (including *Sowerbyella*) and small bryozoans. Weathered Lebanon exposures generally are strewn with saucer-sized fragments of limestone which have rough, uneven surfaces.

In Tennessee Wilson (1949) was able to subdivide the Lebanon into a lower thin-bedded member, a middle massively bedded member, and an upper thin-bedded member. Some thicker beds occur locally within the middle part of the Lebanon in northwestern Georgia, but they are not known to be persistent laterally.

The Lebanon Limestone is approximately equivalent to zone –2 of Allen and Lester (1957) in Chattanooga Valley and in the valley of West Chickamauga Creek.

Carters Limestone

The Carters Limestone was named by Safford (1869, p. 258-268) for exposures along Carters Creek in Maury County, Tennessee. The Carters overlies the Lebanon paraconformably (Wilson, 1949, p. 54). The Carters-Lebanon contact is picked where beds 1 to 2 inches thick are overlain by beds 1 to 6 inches thick. Beds of the lower Carters generally are considerably less fossiliferous than the Lebanon, and weathered pieces are rounded rather than rough or irregular.

The Carters is divided into a lower and an upper member, separated by bentonite T-3 (Wilson, 1949, p. 46). Bentonite T-3 occurs at the base of the upper member of the Carters Limestone; bentonite T-4 is near the top of the Carters.

The lower member of the Carters is about 100 feet thick and consists of three units that in northwestern Georgia are much the same as in Sequatchie Valley, Tennessee. The lowest unit consists of 25 feet of calcilutite and fine-grained calcarenite in 1- to 6-inch beds. The rock is slightly fossiliferous and argillaceous, and is fucoidal as are most Stones River limestones.

In the Mill Creek section the middle unit consists of interbedded gray limestone and olive-gray calcareous mudstone and is at least 8 feet thick and possibly as much as 24 feet thick. The upper unit is medium-gray or medium olive-gray calcilutite or calcisiltite in beds 1 to 13 inches thick. The upper unit of the lower member of the Carters is at least 49 feet thick, and possibly as much as 65 feet thick.

Limestones of the lower member of the Carters are all medium-gray to medium-dark gray, medium-dark brownish-gray and olive-gray, fucoidal, and slightly fossiliferous. The range of beds to as much as 18 inches thick and the comparative scarcity of fossils separates the Carters from the underlying Lebanon.

Bentonite T-3 is yellowish-gray to grayish yellow-green; some is granular, some fissile. Weathered bentonite is soft, easily deformed clay. The bentonite is 4 to 5 feet thick and overlies a bed of chert 3 to 8 inches thick. The chert is olive-gray to dusky yellowish-green and weathers moderate yellowish-brown.

Underlying lower Carters limestones generally contain marine fossils, and in many places the T-3 chert contains chert-replaced marine fossils (brachiopods), indicating that T-3 volcanic ash fell into the sea.

The upper member of the Carters Limestone is 27 feet thick and consists generally of calcilutite with minor amounts of calcisiltite and very fine-grained calcarenite. The limestones are medium-gray to medium-dark gray, light olive-gray, and greenish-gray. The strata characteristically weather light-gray. Some of the rock is mud-cracked, some burrowed, and some contains intraclasts. Beds are 1 to 6 inches thick and average 2 inches. Bedding is even and regular, and some beds are finely cross-bedded. Marine fossils are generally absent.

The upper member of the Carters in northwestern Georgia apparently was deposited in an intertidal environment not conducive to marine life.

Bentonite T-4 is 2 feet thick and occurs within the upper Carters 4 to 10 feet below the top of the formation. The bentonite is grayish-orange and grayish yellow-green. The T-4 bentonite contains abundant biotite flakes and overlies a thin (¾-inch) platy chert. Bentonite T-4 may have accumulated at or near mean sea level in northwestern Georgia and adjacent parts of the Tennessee Valley and Ridge and in Sequatchie Valley, Tennessee. It would be interesting to determine if the occurrence of biotite is diagnostic of subaerial accumulation, or a characteristic of T-4 regardless of depositional environment.

The Carters Limestone is well exposed along both sides of the road between Old Bethel Church and Glass Mill Road, and the upper member is well exposed in the section along the Tennessee, Alabama, and Georgia railroad about 2500 feet east of McLemore Cove Road, near Davis Crossroads, Kensington quadrangle.

The Carters Limestone is equivalent to the 0 zone, zone –1 and probably the upper part of zone –2 of Allen and Lester (1957) in Chattanooga Valley and in the valley of West Chickamauga Creek.

NASHVILLE GROUP

Hermitage Formation

The Hermitage Formation, which was named by Hayes and Ulrich (1903, p. 2) from exposures near the Hermitage community in Davidson County, Tennessee, overlies the Carters paraconformably (Wilson, 1949, p. 61).

In northwestern Georgia the Hermitage consists of 35 feet of argillaceous calcilutite to coarse-grained calcarenite. The contact with the Carters is picked where even-bedded, finely crossbedded, or mud-cracked limestones of the upper Carters are overlain by generally poorly bedded, medium- or olive-gray argillaceous limestone. Poorly preserved Hermitage bedding perhaps is related to the reworking of Hermitage sediments by burrowing organisms (bioturbation). The Hermitage contains numerous fossils of bryozoans, crinoids, brachiopods, and horn corals, and probably was deposited in a subtidal environment.

The Hermitage Formation is well exposed under the powerline (not on map) 1000 feet southwest of Glass Mill Road, and along the Tennessee, Alabama, and Georgia railroad near Davis Crossroads, Kensington quadrangle. It is equivalent to the lower beds of zone +1 of Allen and Lester (1957) in the valley of West Chickamauga Creek.

Cannon Limestone

The Cannon Limestone was named by Ulrich in 1911 for exposures in Cannon County, Tennessee, and a type section designated by Bassler (1932, p. 87-88) was established in Cannon and Rutherford Counties, Tennessee. The Cannon overlies the Hermitage with apparent conformity.

Wilson (1949) described the nomenclature and stratigraphy of the Bigby-Cannon Limestone in Central Tennessee in considerable detail and preferred the use of the dual nomenclature for the formation. Thus, in Central Tennessee workers refer to ". . . Bigby facies and Cannon facies of the Bigby-Cannon limestone . . ." (Wilson, 1949, p. 107).

The dual nomenclature is of little practical use in northwestern Georgia, and the writers prefer the use of Cannon Limestone in a formational sense, rather than as a lithofacies.

The Cannon Limestone consists of medium-dark gray calcilutite to calcarenite in well-defined beds generally 2 to 6 inches thick. *Tetradium* are abundant, as are brachiopods, bryozoans, and gastropods in some beds. The formation is 110 to 120 feet thick in the Chickamauga area and is best exposed between Jake Goodson Creek and Old Bethel Church (fig. 2, Map Number—8).

Chert lenses and nodules are common in the Cannon, and small rectangular chert fragments as much as 1 inch long are useful in mapping Cannon residuum where the formation is not exposed.

The Cannon Limestone is equivalent to the upper zone of zone +1 and zone +2 of Allen and Lester (1957) in the valley of West Chickamauga Creek.

Catheys Formation

The Catheys Formation, which was named by Hayes and Ulrich (1903, p. 2) for exposures along Catheys Creek in Lewis and Maury Counties, Tennessee, overlies the Cannon with apparent conformity. Upper beds of the Cannon in places are argillaceous or silty and weather yellowish-gray. The Cannon-Catheys contact is picked generally within the yellowish-gray-weathering strata, where typical thick beds of the Cannon give way to laminated or very thin- to thin-bedded limestones.

The Catheys Formation in Sequatchie Valley, Tennessee, and in northwestern Georgia consists of two main rock types. Lower beds of the formation are laminated or thin-bedded alternations of silty yellowish-gray-weathering calcilutite and calcisiltite and medium-gray fine-grained limestones. Weathered pieces are characteristically rounded, and the color alternations are strikingly similar to topographic contours; hence, the rock is sometimes called "contour-rock" in the field.

Wilson (1949, p. 144) subdivided the Catheys of Central Tennessee into several lithofacies and referred the lower laminated beds to the "laminated siltstone facies."

In northwestern Georgia and Sequatchie Valley, Tennessee, the laminated siltstone facies is typically unfossiliferous and some beds are mud-cracked, indicating that the strata were deposited in an intertidal environment.

The middle and upper half of the Catheys Formation consists of irregularly bedded medium-gray limestones (lutites to arenites), and is abundantly fossiliferous. Limestone beds are separated by partings or very thin beds of calcareous shale, and the weathered outcrop is strewn with pieces of limestone which have irregular, rough surfaces much like the Lebanon.

Bryozoans and brachiopods are abundant, including *Constellaria,* a characteristic fossil of the Catheys in Central Tennessee (Wilson, 1949). The fossils are little abraded but commonly broken, indicating that they were transported only a short distance before deposition. The middle and upper Catheys probably were deposited in a subtidal environment into which clastics periodically flooded. The most fossiliferous beds are relatively pure limestones and represent accumulations in relatively clear water. Periodic influx of terrigenous mud killed much of the life, presumably in local areas, and remains were preserved in a covering of limy ooze.

The Inman and upper part of the Catheys are well exposed in Lookout Valley along Interstate Highway 59 north of Trenton. The lower member of the Catheys is best seen between Old Bethel Church and Jake Goodson Creek (fig. 2, Map Number—8), and the Catheys-Sequatchie contact is exposed under the powerline 4100 feet south-southeast of Old Bethel Church.

The Catheys Formation is about 250 feet thick in the valley of West Chickamauga Creek. The lower member of the formation is 100 to 110 feet thick and is equivalent to zones +3, +4, and +5 of Allen and Lester (1957) ; the upper member of the Catheys is equivalent to zone +6 of Allen and Lester.

UPPER ORDOVICIAN FORMATIONS

The Catheys Formation is overlain paraconformably by the Inman Formation (Wilson, 1949, p. 177-179) in Lookout Valley, and unconformably by mottled grayish-red calcareous mudstones of the Sequatchie Formation near Chickamauga (fig. 2). The contact with the Inman is picked where medium-gray, thin- to medium-bedded argillaceous limestones are overlain by silty, greenish-gray calcilutites or calcisiltites. In northwestern Georgia the Catheys-Inman contact is best exposed along Interstate Highway 59, 2.8 miles north of the Trenton Interchange in Lookout Valley. The Inman contains red and green shales in Sequatchie Valley, Tennessee, in the Chattanooga area, and Lookout Valley, Georgia, and was included (along with the overlying Leipers) within the Sequatchie by earlier workers.

Upper Ordovician strata show marked facies changes in the Lookout Valley-McLemore Cove region. Red mudstones and calcisiltites of the Sequatchie overlie the Catheys at the nose of Pigeon Mountain between Old Bethel Church and Jake Goodson Creek, Kensington quadrangle, and the Inman and Leipers are absent. The red mudstones apparently grade laterally into Sequatchie lagoonal or shallow-water gray and greenish-gray marine limestones in the 10-mile interval between Chickamauga and Lookout Valley.

The absence of Inman and Leipers in McLemore Cove and in the Interstate Highway 75 roadcut through Taylor Ridge near Ringgold probably is related to the regional unconformity recognized by Butts (1928, p. 133) and Rogers (1961) at the base of the Red Mountain Formation in Alabama.

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APPENDIX

Rock descriptions: Suffixes -lutite, -siltite, -arenite refer to grain size only. Colors are from The Geological Society of America Rock Color Chart, and for dry specimens. The words "even" and "uneven" refer to bedding thicknesses; "regular" and "irregular" refer to bedding surfaces.

Sections were measured with steel tape where possible. Sections up hills or along moderately dipping beds such as in Chattanooga Valley were hand-leveled. The thicknesses of the Murfreesboro Limestone and Catheys Formation were obtained from the geologic map.

I-59 SECTION, LOOKOUT VALLEY, Hooker Quadrangle, Ga.-Tenn. UPPER PART OF CATHEYS FORMATION. Map Number —1, Fig. 1.

Interval	Thickness (feet)	Description
		INMAN FORMATION (upper part not measured)
0.0-6.0	6.0	CALCISILTITE to coarse-grained CALCARENITE, mottled, greenish-gray and grayish-red, with some color in layers; beds 1 inch to 1.5 feet thick, even, irregular, fossiliferous
6.0-9.0	3.0	CALCISILTITE, argillaceous, greenish-gray, with CALCARENITE, medium-grained, medium-gray, in lenses up to 1 inch thick, and partings of SHALE, greenish-gray; one bed, even, irregular, moderately fossiliferous
		BASE INMAN, TOP CATHEYS
9.0-20.2	11.2	INTERBEDDED, CALCISILTITE, argillaceous, olive-gray, and CALCARENITE, medium-grained, medium-gray; beds ½ inch to 4 inches thick, even, irregular but with some uneven lenses, abundantly fossiliferous; vugs as much as 1.5 inches across contain anhydrite
20.2-22.2	2.0	CALCISILTITE, argillaceous, to CALCARENITE, medium-grained, greenish-gray, medium-dark gray, argillaceous, fossiliferous, with partings of calcareous shale; one bed, even, irregular
22.2-25.3	3.1	CALCISILTITE, argillaceous, to CALCARENITE, medium-grained, medium-gray, greenish-gray, light olive-gray; beds ½ inch to 5 inches thick, even, regular, slightly fossiliferous
25.3-27.8	2.5	CALCISILTITE, argillaceous, to CALCARENITE, medium-grained, in lenses as much as 1 inch thick, greenish-gray, light olive-gray; one bed, even, irregular, fossiliferous
27.8-45.1	17.3	CALCISILTITE, medium-gray, to CALCARENITE, coarse-grained, medium-dark gray, argillaceous; beds 2 to 4 inches thick, even, irregular, with partings of gray calcareous shale; very fossiliferous, bryozoans, brachiopods
45.1-46.8	1.7	CALCISILTITE, argillaceous, to CALCARENITE, medium-grained, in lenses as much as 1 inch thick, greenish-gray, light olive-gray, medium-gray; one bed, even, irregular, fossiliferous
46.8-55.2	8.4	CALCISILTITE to CALCARENITE, coarse-grained, medium-dark gray, argillaceous; beds 2 to 4 inches thick, even, irregular, with partings of gray calcareous shale; very fossiliferous, bryozoans, brachiopods.
55.2-60.7	5.5	CALCISILTITE, argillaceous, to CALCARENITE, medium-grained, in lenses as much as 1 inch thick, greenish-gray, medium-gray; beds 1 to 3 feet thick, even irregular; fossiliferous, bryozoans; glauconitic
60.7-90.7	30.0	CALCISILTITE to CALCARENITE, coarse-grained, medium-dark gray, argillaceous; beds 2 to 4 inches thick, even, irregular, with partings of gray calcareous shale; very fossiliferous, bryozoans, brachiopods

OLD BETHEL CHURCH-JAKE GOODSON CREEK SECTION, Kensington Quadrangle, Georgia. LAMINATED SILTSTONE MEMBER OF CATHEYS FORMATION AND CANNON LIMESTONE. Map Number—8, Fig. 2.

Interval (feet from base of upper Catheys)	Thickness (feet)	Description
		CALCISILTITE, medium-dark gray, beds 1 to 4 inches thick, uneven; soil filled with fragments 2 to 8 inches across; lowest exposure of upper member of Catheys Formation
20	20	COVERED, BASE UPPER CATHEYS, TOP LAMINATED SILTSTONE MEMBER
75	55	CALCISILTITE, argillaceous, medium-gray, yellowish-gray, light olive-gray, with grayish-green splotches of glauconite; bedding from laminae to as much as 1 foot thick, even, regular; weathers to rounded outcrops; in some beds yellowish-gray-weathering laminae alternate with medium-gray or light olive-gray limestone; some beds are rippled, some mudcracked; intermittently exposed
88	13	CALCILUTITE to CALCARENITE, fine-grained, medium-dark gray, some slightly argillaceous and weathers yellowish-gray, some beds have brownish-gray argillaceous splotches or fucoids, bedding 1 inch to 1 foot thick, even, irregular
124	36	CALCILUTITE to CALCISILTITE, medium-gray to medium-dark gray, with argillaceous calcilutite to calcisiltite, yellowish-gray-weathering; beds even, regular, in alternating laminae or beds as much as 6 inches thick of argillaceous and less argillaceous limestone; intermittently exposed
	BASE CATHEYS, TOP CANNON	
234	110	CALCILUTITE to CALCISILTITE, medium-gray to medium-dark gray, weathers light olive-gray, some argillaceous; upper beds are more argillaceous and weather yellowish-gray; bedding generally 4 inches to 1 foot thick, even, irregular, weather rounded. Beds about 15 feet above base are laminated "contour rock," about 10 feet thick; some argillaceous, medium-dark gray, light olive-gray, or brownish-gray weathering beds 2 to 3 feet thick and some fossiliferous fragmental beds of fine-grained calcarenite are in the section. *Tetradium* are abundant throughout
251	17	COVERED, base of Cannon estimated to be 10 feet below lowest exposure of Cannon. Top uppermost exposure of Hermitage

DAVIS CROSSROADS SECTION, Kensington Quarangle, Georgia. Section measured along north side of Tennessee, Alabama, and Georgia Railroad, CANNON LIMESTONE, HERMITAGE FORMATION AND CARTERS LIMESTONE. Map Number—3, Fig. 1.

Interval (feet from top of section)	Thickness (feet)	Description
		CANNON LIMESTONE, lower part
0.0-30.5	30.5	CALCILUTITE, medium-dark gray, with some partings of argillaceous limestone; beds ½ inch to 6 inches thick, even, some regular; fossiliferous, brachiopods, bryozoans, and gastropods, near top, *Tetradium* abundant; petroliferous; some beds with a few intraclasts
		BASE CANNON, TOP HERMITAGE
30.5-32.0	1.5	Gradational zone as below, but with some *Tetradium*
32.0-65.5	33.5	CALCILUTITE to CALCARENITE, coarse-grained, olive-gray, medium-gray, argillaceous, with partings of argillaceous limestone; bedding about 1 inch thick, even, very irregular, cobbly weathering; fossiliferous, bryozoans, crinoids, brachiopods, horn corals
		BASE HERMITAGE, TOP CARTERS (UPPER MEMBER)
65.5-71.5	6.0	CALCILUTITE to CALCARENITE, very fine-grained, medium-gray to medium-dark gray; beds 1 to 6 inches thick, about 2 inches average; even, regular; with partings of argillaceous limestone; with some intraclasts; some beds finely crossbedded some mudcracked, some with calcite-filled burrows
71.5-72.0	0.5	SHALE, calcareous, light olive-gray, fissile
72.0-74.0	2.0	BENTONITE, T-4, grayish-orange, grayish yellow-green, with abundant biotite; with thick chert at base, dusky yellow, about ¾ inch thick, platy
74.0-84.5	10.5	CALCILUTITE, medium-gray, greenish-gray, argillaceous, beds 2 to 8 inches thick; with interbeds of CALCARENITE, very fine-grained, medium-dark gray, beds 1 to 4 inches thick, even, regular
84.5-91.5	7.0	CALCILUTITE, to CALCISILTITE, medium-gray to medium-dark gray; beds ½ inch to 4 inches thick, even, regular; some weathers very light-gray; with small amounts of intraclasts, mudcracked, some beds finely crossbedded
91.5-92.5	1.0	SHALE, calcareous, yellowish-gray, fissile, tough
92.5-96.5	4.0	BENTONITE, T-3, yellowish-gray, grayish yellow-green, fissile, granular, soft; CHERT, olive-gray, dusky yellowish-green, bed about 4 inches thick, even, regular, at base of clay
		(LOWER MEMBER)
96.5-108.5	12.0	CALCILUTITE, medium-gray to medium-dark gray; with argillaceous splotches and partings; beds ½ inch to 6 inches thick, even, irregular; moderately fossiliferous, with brachiopods, crinoids, bryozoans, cup corals
		COVERED

MILL CREEK SECTION, CHATTANOOGA VALLEY, Kensington Quadrangle, Georgia. CARTERS, LEBANON, AND RIDLEY LIMESTONES. Fig. 4, and Map Number—2, Fig. 1.

Interval (feet below T-4)	Thickness (feet)	Description
———	———	BENTONITE, T-4, with weathered biotite, poorly exposed
0.0-18.0	18.0	CALCILUTITE to CALCISILTITE, light olive-gray, medium-gray, some argillaceous; beds ½ inch to 1 inch thick, even, regular, some with irregular surface, some mudcracked
18.0-23.0	5.0	BENTONITE, T-3, as in Davis Cross Roads Section. Chert at base is 3 to 8 inches thick, dusky yellowish-green, moderate yellowish-brown (weathered surface)
23.0-72.0	49.0	CALCILUTITE to CALCISILTITE, medium-gray, some medium olive-gray, with light olive-gray argillaceous splotches and partings; bed 1 to 18 inches thick, even, irregular; slightly fossiliferous, with gastropods, crinoids, brachiopods, horn corals
72.0-88.0	16.0	COVERED
88.0-96.0	8.0	INTERBEDDED, CALCILUTITE to CALCARENITE, fine-grained, and some limestone-pebble CONGLOMERATE, medium-gray to medium-dark gray, medium-dark brownish-gray, olive-gray, some argillaceous, and MUDSTONE, calcareous, olive-gray; beds 1 to 3 inches thick, even, some irregular; intermittently exposed
96.0-121.0	25.0	CALCILUTITE to CALCARENITE, fine-grained, medium-gray to medium-dark gray, medium-dark brownish-gray, slightly argillaceous; beds 1 to 6 inches thick, even, irregular, with argillaceous splotches and partings; slightly fossiliferous, with brachiopods, bryozoans, gastropods, cephalopods, crinoids
		BASE CARTERS, TOP LEBANON
121.0-234.0	113.0	CALCILUTITE to CALCARENITE, coarse-grained, medium-gray to medium-dark gray, slightly argillaceous; beds ½ inch to 4 inches thick, generally 1 to 2 inches, even, irregular, with argillaceous splotches. Some very fossiliferous with numerous brachiopods, bryozoans, cephalopods, crinoids, *Sowerbyella* abundant in some beds; exposed intermittently on hill, exposure strewn with saucer-sized fragments
		BASE LEBANON, TOP RIDLEY
234.0-237.0	3.0	CALCARENITE, medium- to very coarse-grained, medium-light gray to medium-gray; beds 1 to 8 inches thick, even, irregular, fossil-fragmental
237.0-266.0	29.0	COVERED, but with beds of CALCILUTITE, olive-gray, some argillaceous, and CALCARENITE, medium- to very coarse-grained, medium-gray, brownish-gray, olive-gray; exposed beds as much as 4 inches thick, even, some irregular; fossiliferous, with trilobite, bryozoans, crinoids

Interval (feet below T-4)	Thickness (feet)	Description
266.0-284.0	18.0	CALCILUTITE to CALCARENITE, coarse-grained, medium-dark gray, medium-dark brownish-gray; beds 1 to 8 inches thick, even, irregular, with argillaceous splotches and partings; fossiliferous, with brachiopods, crinoids, gastropods
284.0-293.0	9.0	COVERED
293.0-330.0	37.0	CALCILUTITE to CALCARENITE, coarse-grained, medium-dark gray, medium-dark brownish-gray; beds 1 inch to 2 feet thick, even, outcrops rounded, with argillaceous partings and splotches; with a few irregular lenses of chert, dark-gray, ½ inch to 1 inch thick, lenses up to 6 inches long; moderately fossiliferous, with brachiopods, bryozoans
330.0-348.0	18.0	COVERED
348.0-389.0	41.0	COVERED, but with float and beds of SHALE, yellowish-gray and dusky-yellow, fissile, and CALCILUTITE to CALCISILTITE, light olive-gray, argillaceous
389.0-427.0	38.0	CALCILUTITE to CALCARENITE, coarse-grained, medium-dark gray, some argillaceous; beds 1 to 18 inches thick, even, irregular, with argillaceous partings and splotches; fossiliferous, with gastropods, brachiopods, crinoids
427.0-462.0	35.0	MUDSTONE, calcareous, yellowish-gray, dusky-yellow, with a few beds of CALCISILTITE, argillaceous, medium-gray, light olive-gray, beds as much as 4 inches thick; poorly exposed
462.0-496.0	34.0	CALCILUTITE, medium-gray to medium-dark gray, light olive-gray, some with argillaceous splotches and partings; beds ⅛ inch to 8 inches thick, some beds platy, outcrops rounded; intermittently exposed in field
		BASE RIDLEY, TOP MURFREESBORO
496.0-511.0	15.0	CALCILUTITE, medium-gray to medium-light gray; beds 2 inches to 2 feet thick, even, some irregular; intermittently exposed on west side of railroad in field near Mill Creek
		Intermittent exposures, not measured, on east side of railroad, in field and woods near Mill Creek

CHICKAMAUGA QUARRY SECTION, Kensington Quadrangle, Georgia. POND SPRING FORMATION, MIDDLE MEMBER. Map Number—4, Fig. 2.

Interval (feet from uppermost exposure)	Thickness (feet)	Description
0.0-6.0	6.0	CALCISILTITE, argillaceous, mottled greenish-gray and grayish-red; beds 1 to 2 feet thick, even, irregular; weathers to yellowish-gray and grayish-red shale
Base upper member of Pond Spring, top middle member of Pond Spring		
6.0-8.5	2.5	CALCILUTITE, argillaceous, medium-gray or yellowish-gray; beds 6 inches to 1 foot thick, even, irregular

Interval (feet from uppermost exposure)	Thickness (feet)	Description
8.5-10.2	1.7	CALCILUTITE, laminated, as below but in beds 2 to 3 inches thick
10.2-12.2	2.0	CALCILUTITE, light olive-gray; beds laminated to ½ inch thick, even, irregular, show sedimentary slump features
12.2-17.7	5.5	CALCILUTITE, medium-gray, and CALCILUTITE, argillaceous, yellowish-gray and light olive-gray; beds ½ foot to 1 foot thick, even, irregular
17.7-21.2	3.5	COVERED
21.2-27.2	6.0	INTERBEDDED, CALCILUTITE, and CALCILUTITE, argillaceous, medium-gray, light olive-gray, some beds glauconitic; beds 2 inches to 1 foot thick, even, irregular
27.2-38.2	11.0	CALCILUTITE, medium-light gray to medium-dark gray with some light olive-gray; beds 1 to 2 feet thick, even, irregular
38.2-42.2	4.0	CALCILUTITE to CALCISILTITE, argillaceous, medium-gray, some light olive-gray, some beds with intraclasts, some fossil-fragmental; beds generally 1 to 3 feet thick, even, irregular
42.2-67.2	25.0	CALCILUTITE to CALCISILTITE, medium-light gray to medium-gray, some light olive-gray, some beds with intraclasts, some fossil-fragmental; beds generally 1 to 3 feet thick, even, irregular
67.2-70.0	0.8	CALCILUTITE, medium-dark gray; one bed, even, irregular
		Base middle member of Pond Spring, top lower member of Pond Spring
70.0-82.0	12.0	CALCILUTITE to CALCARENITE, very fine-grained, mostly CALCISILTITE, light-gray to medium-light gray, some beds mottled greenish-gray and grayish-red and weather yellowish-gray; beds 6 inches to 2 feet thick, even, irregular; some beds are silty or sandy (very fine-grained) and have thin weathering crusts, some beds are laminated, some have intraclasts
		Base of Quarry, water level

KETNER BRANCH SECTIONS, Kensington Quadrangle, Georgia. POND SPRING FORMATION, LOWER MEMBER. Map Numbers—1, 2, and 3, Fig. 3.

Interval (feet below base of middle member)	Thickness (feet)	Description
		Section is exposed on the south bank of West Chickamauga Creek, and in fields south of the creek about 2000 feet northwest of Ketner Branch.
		Basal exposures, Middle member of Pond Spring Formation
0-15	15	COVERED

Interval (feet below base of middle member)	Thickness (feet)	Description
15-25	10	CALCILUTITE to CALCISILTITE, argillaceous, greenish-gray, grayish-red, mottled, some yellowish-gray with small amounts of medium-gray calcilutite; poorly exposed
25-35	10	CALCILUTITE, medium-gray, some slightly argillaceous, beds 1 inch to 1 foot thick, even, irregular
35-57	22	CALCISILTITE, argillaceous, and MUDSTONE, calcareous, grayish-red and greenish-gray, mottled; bedding uneven; poorly exposed

Section is exposed in fields 300 to 400 feet north of Ketner Branch between McLemore Cove Road and West Chickamauga Creek. Section continuous with above.

57-59.5	2.5	CALCISILTITE, medium-light gray, light olive-gray; one bed, even, irregular, marks upper limit of rock quarried for building stone
59.5-85.5	26	CALCISILTITE, argillaceous, some mottled, greenish-gray and grayish-red, some light greenish-gray, medium-gray, glauconite common; beds 6 inches to 2 feet thick, even, irregular, weathers to rough angular pieces; quarried for building stone, upper 15 feet preferred
85.5-135.5	50	CALCILUTITE, light-gray, some slightly argillaceous (Mosheim type), with some beds of calcisiltite, light greenish-gray, porous; beds generally 6 inches to 2 feet thick, even, outcrops rounded

Section exposed in fields and along secondary road 500 to 1500 feet southwest of Ketner Branch. Section approximately continuous with above.

135.5-138.5	3	CALCILUTITE, medium-gray, slightly argillaceous; beds 6 inches to 1 foot thick, outcrops rounded
138.5-143.5	5	COVERED
143.5-147.5	4	CALCISILTITE to CALCARENITE, fine-grained, light-gray, some mottled greenish-gray and grayish-red, some light greenish-gray and grayish-red, some light-gray, some mottled greenish-gray and grayish-thick, even, outcrops rounded
147.5-157.5	10	SILTSTONE, calcareous, grayish-red, poorly exposed
157.5-167.5	10	DOLOSILTITE and CALCISILTITE, dolomitic, very light- to light-gray, light greenish-gray; beds generally 6 to 18 inches thick, even, regular, porous, weathered outcrops rounded
167.5-169.5	2	CONGLOMERATE; pebbles to boulders as large as 1 foot across of dolarenite, fine-grained, medium-light gray, sugary, are in a matrix of dolosiltite, light greenish-gray, porous, glauconitic (?)

Base Pond Spring Formation, top Knox

		DOLARENITE, very fine- to fine-grained, medium-light gray, sugary, irregularly bedded, weathers to rough irregular surfaces

STRATIGRAPHY OF THE CONASAUGA GROUP IN THE VICINITY OF ADAIRSVILLE, GEORGIA

By

K. Spalvins

Adapted from an M. S. thesis at
Emory University
Atlanta, Georgia

Sponsored by Georgia Department of Mines, Mining
and Geology

CONTENTS

ABSTRACT

The mapped portion of the Adairsville quadrangle is located in the Valley and Ridge province of northwest Georgia.

The Conasauga Group was divided and mapped on the basis of stratigraphic position and lithology. The units are the Maryville Limestone, Nolichucky Shale, and the Maynardville Formation.

The major structure is an overturned anticline with a reverse fault near its southern end.

All three units have economic potential. Most of the Maryville Limestone is a marginally potential cement grade material. The Nolichucky Shale is brick, quarry tile, and roofing tile material. The Maynardville dolostone has served as a crushed rock source.

INTRODUCTION

Location and Size of Area

The investigated area is in the southwest quarter of the Adairsville 15′ quadrangle, Bartow County, Georgia.

This portion of the quadrangle is bounded by the 34° 15′N and 34° 22½′N parallels and the 84° 52½′W and 85° 00′W meridians.

The quadrangle is served by the Nashville, Chattanooga, and St. Louis Railroad, U. S. Highway 41, Interstate Highway 75, and Georgia Highway 140 as well as many secondary roads. Adairsville, the main municipality, is located at the northern edge of the area (fig. 1).

Topography

The area is a part of the Oothkalooga Creek valley, which is located in the Rome Valley (Campbell, 1925, p. 141) of the Valley and Ridge province (Fenneman, 1938, p. 274).

The hills bounding the Oothkalooga Creek valley range to an altitude of 1,120 feet, 1,000 feet being average, while the elevations on the valley floor vary from 680 to about 800 feet.

Conasauga Group forms the floor and sides of the Oothkalooga Creek valley. The floor of this shallow, southward converging valley consists of low rolling hills. The bounding hills are covered by the cherty residual soil of the Knox Group.

Drainage

The Oothkalooga Creek valley is drained by the north-flowing Oothkalooga Creek and the south-flowing Connesena Creek. Both are subsequent and form a dendritic drainage pattern.

Vegetation

The well-forested valley rims contrast sharply with the topographically more gentle farmland areas. The highland pulpwood areas are underlain by cherty residual soil from the Knox Group which retards erosion and tends to form ridges (Swingle, 1959, p. 22). The valley farmland consists of shale, carbonate residuum, and alluvium material. The shale develops a thin soil and appears as light-colored fields on aerial photographs. The carbonate re-

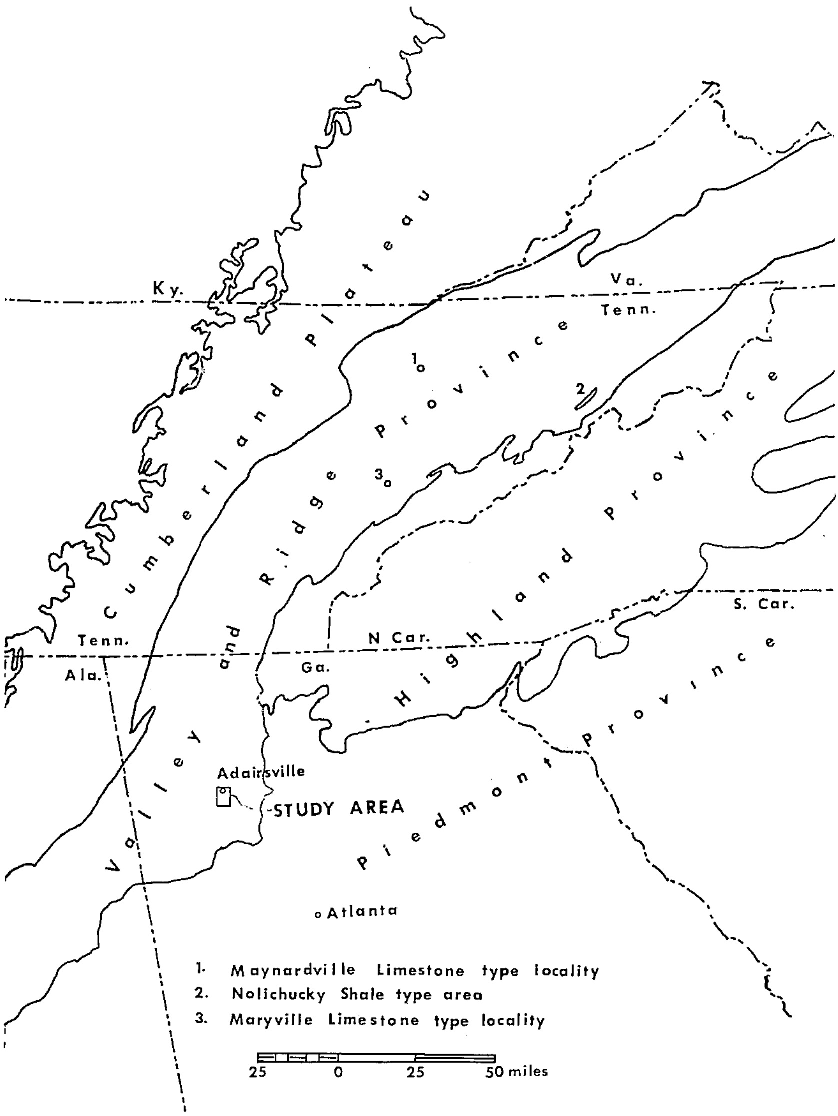

Figure 1: Index map showing the mapped area and the relationship to the type locations.

siduum and alluvium give a deep, rich, clay soil that has good moisture holding characteristics and is visible as slightly darker areas on aerial photographs.

Previous Work

The first works of geologic importance, dealing with the Conasauga Group of northwest Georgia, were by Hayes (1891) and Spencer (1893). Detailed studies have been published by: Kesler (1950), Munyan (1951), Cribb (1953), Stuart (1956), Smith, W. L. (1958), Reighard (1963), and Smith, J. W., and Spalvins (1967).

Purpose of Investigation

The purpose of this investigation was to divide the Conasauga Group into mappable units, obtain data on the geologic structure, and study the economic geology.

Methods of Investigation

The units were located and plotted on a topographic map with the aid of aerial photographs. Locations of the contacts were based principally upon evidence from the residuum. Microscopic methods and chemical, x-ray, and differential thermal analyses were used.

Acknowledgments

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STRATIGRAPHY

Regional Stratigraphy

The Conasauga Shale was named by Hayes for "alternating beds of limestone and calcareous shale" (Hayes, 1891, p. 143; Hayes in Walcott, 1892, p. 304) exposed along the Conasauga River in Whitfield and Murray Counties, Georgia. Its general outcrop pattern follows the arc-like shape of the Valley and Ridge province across the State. The Adairsville quadrangle lies near the southeasternmost exposure. The group's exact thickness in Georgia is not known due to poor exposures, complex and obscure structures, and uncertainty of previous Conasauga groupings. Estimates vary from 500 to 4,000 feet. Smith, J. W., and Spalvins (1967, p. 90) estimate a thickness of about 3,500 feet in Bartow County. Good exposures in Tennessee have made it possible to locally delineate a maximum of six formations within the group. Some of these different phases have been recognized and mapped in Georgia (Cressler, 1963, 1964a, 1964b; Smith, J. W., and Spalvins, 1967).

The oldest formation in the study area in the Maryville Limestone of the Middle Cambrian. It first appeared in print in 1894 (Campbell, p. 2) but was described by Keith (1895, p. 3). Resser (1938, p. 20, table 1) divided the Maryville into the *Olenoides* and *Holteria* faunal zones of the Middle Cambrian.

The Nolichucky Shale first appeared in print in 1894 (Campbell, p. 2) and was described by Keith (1896, p. 2) in Tennessee. Resser (1938, p. 15) says that the Nolichucky Shale is characterized by beds and lenses of limestone that appear to be at no fixed horizon within the formation. The thickness of this formation varies but is between 400 and 700 feet in Georgia (Resser, 1938, p. 15).

The Nolichucky-Maynardville contact is gradational (Safford, 1869, p. 205; Cribb, 1953, p. 26, 41; Stuart, 1956, p. 6; Reighard, 1963, p. 27) from carbonate above to a shale below and is here drawn at the base of the lowest carbonate bed that is several feet thick.

What appears to be the Maynardville Limestone was first referred to by Safford (1869, p. 205) but was named and described in Tennessee by Oder (1934, p. 474-476, 494-497).

Swingle (1959, p. 14) divided the Maynardville into a lower and upper unit. The lower is a 275 to 300 feet massive blue argillaceous limestone that appears ribboned upon weathering. Thinly bedded light-gray dolostone, 50 to 75 feet thick represents the upper unit. Its upper part consists of alternating laminae of crystalline dolostone and light- to dark-gray silty limestone. Above this occurs a gray silty dolomite in 1 to 3 feet thick beds. He also noted the presence of a brecciated zone (1959, p. 47).

Oder and Bumgarner (1961, p. 1021-1028) have made the most complete and detailed columnar description of the Maynardville to date. They divided the formation into 5 zones.

In Tennessee, at the contact between the Maynardville and the overlying Copper Ridge Dolostone, occurs a thin but widespread sandstone bed (Collins, 1958, p. 172-183).

Cressler (1963, 1964a, 1964b) has mapped the Maynardville in Georgia. He describes it as a thick-bedded limestone (1964a, p. 5) with many stylolites at the top (1964b, p. 8). The thickness is estimated to be about 300 feet (1963, fig. 2).

Generally, a chert-free residuum forms an orange soil (Swingle, 1959, p. 15). In places a ropy black chert and a tripoli zone are present (Cribb, 1953, p. 26).

Geologists have tried to distinguish the basal unit of the Knox Group, the Copper Ridge Dolostone, from the upper Conasauga or Maynardville in Georgia in a number of different ways. This is a significant boundary in that it is the Dresbach-Franconian time contact (Howell, et al., 1944, chart I). The most mappable and widely applied criteria is the presence or absence of a certain distinctive chert or cherty residuum (Hayes, 1900, p. 6; Butts, 1926, p. 86; Resser, 1938, p. 17-18; Cribb, 1953, p. 26; Swingle, 1959, p. 35; Salisbury, 1961, p. 12; Cressler, 1963, p. 11; Croft, 1963, p. FF13).

A tripoli zone has also been used to delineate the contact and Cribb (1953, p. 26) was able to locate parts of the upper contact on this basis. Swingle (1959, p. 14) also notes tripoli zones at the upper contact but thinks that tripoli is derived from the weathering of the chert (Swingle, 1959, p. 77) and therefore might not be a stratigraphic indicator.

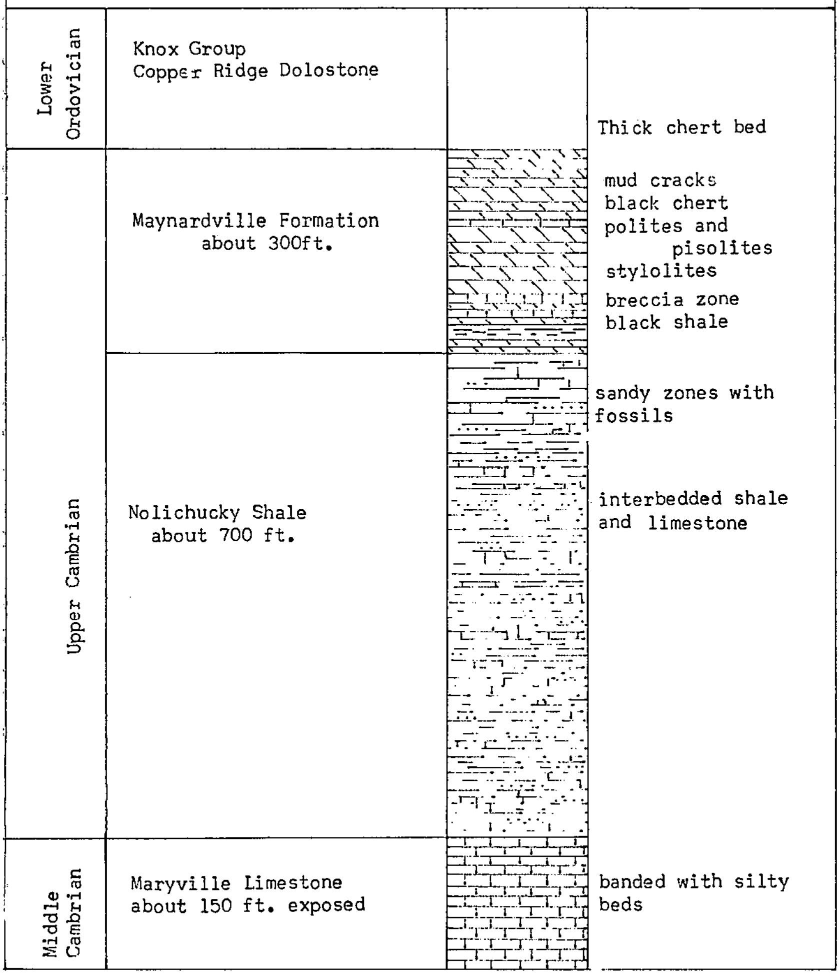
In certain localities the dolostone is a thick-bedded, gray (Butts and Gildersleeve, 1948, p. 16), massive, and coarse-grained rock (Rodgers, 1953, p. 48) which when broken has an asphaltic odor (Cressler, 1964a, p. 7). When this rock is present, the boundary is drawn at the base of the lower-most massive dolostone bed.

Local Stratigraphy

Maryville Limestone

About 200 feet of what is probably the Maryville Limestone is exposed in the mapped area. It has a total thickness of about 650

GENERALIZED STRATIGRAPHIC COLUMN



feet (Smith, J. W., 1966, personal communication) at Cass Station, about 6 miles southeast of the mapped exposures. There is no reason to believe that there is any difference in the thickness between the two localities. The Maryville is folded into a number of small synclines and anticlines that form a series of valleys and ridges in the center of the major fold.

The rock consists of alternating bands of limestone, silty limestone, argillaceous limestone, and dolostone laminae. It is dark gray, fine grained, crystalline, and thin- to medium-bedded. On the fresh surfaces the ribboning is not pronounced, but on weathered surfaces, it becomes very distinctly ribboned as the silty thin dolostone zones become lighter in color and stand in relief. Some of the limestone bands consist of fragments and bodies of clear, medium-grained (.5 to 1.2 mm) calcite crystals. Dolostone laminae are thin, scattered, and have pyrite grains associated with them. In some places, calcite stringers crosscut the rock. The outcrops are well rounded by weathering.

Insoluble residue content averaged 8% by weight in 5 grab samples after treatment with cold HCl. Compositionally, the insoluble materials were made up primarily of dolomite and quartz fragments.

The Maryville-Nolichucky contact is distinct in areas where the Maryville forms resistant ledges on ridges capped by the Nolichucky.

No fossils were observed.

Nolichucky Shale

The Nolichucky Shale consists of regularly alternating beds of thinly laminated shales, limestones, and sandy layers. The shales predominate and range from laminae to tens of feet in thickness. Gray or dark green when fresh, it becomes a red brownish-yellow upon weathering.

Where interbedded, the shale forms the more prominent beds and the carbonate occurs as a recessive red-brown clay layer. The shale-carbonate weathering relationship is reversed in newly formed drainage channels where mechanical disintegration predominates, against which the carbonate is the more resistant.

The upper limestone that was described by Keith (1896, p. 2) was not observed. If it is present it has been included within the carbonates of the Maynardville Formation.

The Nolichucky-Maynardville contact is very distinctive in that it occurs between two different lithologies. The contact is drawn at the appearance of the first major shale fragments in the residuum when going down in the section.

The thickness of the Nolichucky could not be precisely determined. Resser (1938, p. 15) thought it to be a maximum of 700 feet in Georgia. This appears to be about the thickness in the mapped area but is an estimate at best due to the structural contortions of the shale.

As a general rule fossils are scarce throughout the area, even though the Nolichucky is very fossiliferous in other areas (Resser, 1938, p. 33-34). Extensive weathering and crosscutting cleavage bedding relationships in the shale make collecting difficult. Some sandy zones produce badly fragmented fossils. Numerous free cheeks, glabellas, thoracic segments, and pygidia of trilobites and a brachiopod (*Linguella*) were observed. Most were only molds. Fragmentary evidence indicates that at least two different genera of trilobites existed.

Petrographic analysis shows quartz grains scattered in the very fine groundmass of the shale. Differential thermal analyses of clay samples were compared to the standard illite from Morrison, Illinois, and to data obtained by Grim and Rowland (1944, p. 11). These indicate that the samples contain illite. X-ray data re-enforced this conclusion.

Maynardville Formation

This unit is between 250 and 350 feet thick in the area. Of the few outcrops observed, most occurred in the upper half of the formation, so that the stratigraphic sequence is incomplete and generalized. It consists primarily of thin- to thick-bedded, finely laminated to massive, light- to dark-gray dolostone and limestone.

The lowest exposed beds are thin (2″ to 4″) beds of silty limestone containing the same brachiopod as the upper Nolichucky. These are followed by a sequence of thinly interbedded limestone and dolostone. A black bed of shale of undetermined thickness and a breccia zone are apparently located above them. The breccia of the Maynardville is thought to be stratigraphic, but it was observed in only two outcrops. One exposure was on the apparently unfaulted east limb; the other near the fault. Both exposures appear to be at about the same horizon, but this could not be definitely established. The upper part of the formation is medium to thick bedded. It contains oolites, pisolites, stylolites, varves, mud cracks, and distinctive dark-gray to black chert layers.

Above these features and below the lower most Knox chert occurs a thin (about 2″) bed of sandstone. This might be a number of beds since most examples were observed as float. Its widespread occurrence, small thickness, and stratigraphic location seem to indicate a wind carried origin.

The Maynardville weathers to a deep-red to red-brown residuum and often leaves a series of exposed pinnacles in eroded areas. The residuum, in contrast to that of the Knox, is virtually devoid of any kind of large particles. However, near the Nolichucky-Maynardville contact a series of platy fragments can be found in the residuum. These can be easily confused with real shale fragments.

The oolites (.05 to .1 mm in diameter) are recrystallized but some still maintain a faint layered structure.

The pisolites are elongated, (longitudinal size range of .3 to 1.0 mm) and also recrystallized; some are still banded. With the pisolites are found some bodies of structureless agglutinated material or pseudopisolites.

Some stylolites form boundaries between the different types of textures. Stylolites crosscutting oolites were also observed.

Fine, regular layering is very distinctive in places. Individual layers are under 0.1 mm thick and persistent. Mud cracks occur as distinctive polygonal features about 10 inches in diameter. They were observed at only one locality; therefore, their stratigraphic or horizontal range is unknown.

The distinctive black chert of the upper Maynardville occurs in extremely fine-grained lenticular masses. Some of the chert has weathered to a soft tan material.

The weathered sandstone is composed of well-sorted, slightly indurated quartz grains and it possibly had a carbonate matrix.

Knox Chert

The basal Copper Ridge Dolostone was not observed as bedrock in the map area. All delineations were done on the basal chert that occurs as solid to porous, tough to rotten, blocky and jagged masses in the residuum. It may be banded, oolitic, homogeneous, or contain cryptozoons. The homogeneous masses are the most abundant. The color ranges from a light tan to a deep gray, with red and black areas on some blocks. Generally, the blocks are a foot or more in diameter; if smaller they are very abundant.

This chert forms a very characteristic exposure in road-cuts.

Quaternary Alluvium

Alluvium was not mapped due to its thin, low volume deposits and difficulty in distinguishing it from carbonate residuum.

STRUCTURE

Regional Structure

The major regional structures are the Cartersville and Rome Faults and a series of northeast to southwest striking anticlines and synclines. These two low angle faults form thrust sheets of great displacement (Rodgers, 1949, p. 1653-1654). The Rome Fault probably passes under the mapped area and presumedly sheared the beds off the basement, making the deformation a shallow phenomena (King, 1950, p. 642).

The Knox Group and the Maynardville Formation probably functioned as the conductor of lateral thrusts (Hayes, 1891, p. 142). The Nolichucky Shale is the first weak unit under the rigid Knox Group and underwent folding and faulting. The major folding probably occurred during the Appalachian Orogeny.

Local Structure

Folds

The author agrees with Croft (1963, map) and Butts and Gildersleeve (1948, p. 16) that the Oothkalooga Valley is a structural anticline. The gently sloping east limb has a general N30°E to N45°E strike. The western limb is sharply overturned, probably isoclinal at the north and becomes more open towards the south (Croft, 1963, map). The overturned relationship cannot be observed in any single outcrop. This major anticline has about a 5°S plunge.

A number of small anticlines occur within the area; those observed within the Maryville appear to be normal, while those in the Nolichucky are overturned.

Faults

According to Croft (1963, map), two large faults (one in the northern area, the other in the south) cut the western limb parallel to the general strike of the anticline. Based on present observation, the existence of the northern fault is doubtful. The southern fault is present, as indicated by White and Denson (1966, pl. I). Its precise and previous locations are obscured by the road and the railroad. Its presence is based on a broken stratigraphic sequence.

In the south, a cross structure causes variations up to 90° from the overall strike. White and Denson (1966, pl. I) show a fault in the Knox in the adjacent area. Lack of sufficient exposures in the Conasauga obscure its relationship in the map area.

Joints

The number of joint systems and the extent of their development varies within the outcrop. Joints parallel to the major fold axis direction are the most abundant.

CORRELATION

The Maryville, Nolichucky, and Maynardville formations near Adairsville are very similar in appearance to their type localities in Tennessee. The distance between the two areas is about 200 miles southwest along the strike. The few minor changes that were noted in the formations between the two areas were mainly associated with the increased weathering. Lithology and stratigraphic position are the useful basis of correlation.

ECONOMIC GEOLOGY

Since carbonates and shale have a low unit value, the economic significance of the upper Conasauga Group lies in its high place value. The location of the Adairsville exposures on good transportation to the Atlanta area will be a major determining factor in development.

Crushed Rock

Presently the Conasauga carbonates are mined for road aggregate in areas outside the quadrangle, but crushed rock has been produced in the quadrangle. Old quarries are located on old U. S. Highway 41, near Connesena Mountain, and at Cement, Georgia. Crushed rock quarries in the Maynardville are operated east of Adairsville on Georgia Highway 140, and near Calhoun on Georgia Highway 53 to supply the construction of Interstate Highway 75. As I-75 is extended, the Maynardville Formation will become economically significant. Locations within the quadrangle in which crushed rock quarries could easily be developed are situated in the northeast and south. In addition, any one of the abandoned quarries could probably be reopened for this type operation.

Cement

Natural cement was produced from the Maynardville at Cement, Georgia, near the turn of the century (Butts and Gildersleeve, 1948, p. 94). At first the room and pillar method was used to obtain limestone. The material was marginal and produced a slow setting product, which eventually became non-competitive. The mine then was converted to an open-pit crushed rock operation.

Presently, no cement rock is mined in the quadrangle. At Cass Station about 2 miles south of the area, the Marquette Quarry produces rock for cement from the Maryville Limestone (Smith, J. W., 1966, personal communication). The Marquette operation is marginal as the Mg content is near the maximum limit. Despite the low quality of the rock, the Southern Cement Company has been doing exploratory drilling in the surrounding area. Although, the early quarrying for limestone in the Adairsville quadrangle was from the Maynardville any future development must use the Maryville as its source. The interbedded nature of the Maynardville sequence makes it hard to control quality in a large scale mechanized operation. Much of the Maryville Limestone is by the railroad line making shipping convenient. Stratigraphic units within it have met specifications for portland cement in the past and indicate that large modern mines could be opened in the Maryville Formation for this purpose.

Shale

The difficulty in using the shales of the Conasauga as a clay source is the illite composition, which results in a lack of plasticity and strength (Veatch, 1909, p. 116).

Tile and brick plants, using these shales as raw material are, or have been, operated in various northwest Georgia localities. The largest of these operations is the Dalton Brick and Tile Co. of Dalton, which has been in production since 1924 (Cribb, 1953, p. 38). At the northern edge of the quadrangle, on Georgia Highway 140 next to the railroad tracks is the site of the Adairsville Brick Co. Started in 1906-1907, it manufactured common and face brick from the adjacent shale pit. The operation was taken over by B. Mifflin Hood Company (Smith, R. W., 1931, p. 243) which in 1926 changed the product to roofing tile and used adjacent colluvial clay instead of the shale as source material (Butts and Gildersleeve, 1948, p. 97). This operation was abandoned sometime before 1948 (Butts and Gildersleeve, 1948, p. 97) and was renewed in 1965-1966 by the Georgia Quarry Tile Co. They changed the product to quarry tile and brought in the shale by truck. The operation proved economically unfeasible as set up, and the plant closed in the latter part of 1966.

Fossil Localities

Fossils are usually located in the sandy zones of the Nolichucky. Only two fossil locations were found. The most productive one is on Rock Fence Road, about one half mile west of the intersection with Hall's Station Road. The other is in the first large road cut on Hall's Station Road, going south, from the intersection of Georgia Highway 140.

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LATE PRECAMBRIAN AND EARLY PALEOZOIC EROSIONAL AND DEPOSITIONAL SEQUENCES OF NORTHERN AND CENTRAL VIRGINIA

By

A. S. Furcron

Georgia Department of Mines, Mining and Geology

Atlanta, Georgia 30334

CONTENTS

ABSTRACT

Precambrian granodiorite, granite, and migmatite are surface-exposed in the Blue Ridge and Piedmont of the Blue Ridge province of northern and central Virginia. Unconformably over these rocks were deposited the Late Precambrian Lynchburg Group, composed of fragments of the older Precambrian igneous complex. The Lynchburg Group was folded and metamorphosed in the Late Precambrian and crumpled and infolded with the basement dipping steeply southeastward. Late Precambrian erosion removed most of the Lynchburg from the central and western parts of the Province where is exposed the earlier Precambrian igneous complex.

Following this profound erosion interval, the Swift Run pyroclastics were deposited. Much of this material is tuffaceous but much of the first coarser beds are fragmented, earlier Precambrian basement or Lynchburg gneisses deposited with more or less ash. It is thickest across the central Virginia area, patchy in the Blue Ridge range, and thin to absent in northern Virginia. Later, widespread fissure eruptions produced more basic Catoctin flows which sputtered out westward in Unicoi and Loudoun times as local flows and ash beds. The Swift Run and Catoctin were folded and metamorphosed in the Paleozoic.

The Blue Ridge was a positive area at least in the Lower Cambrian and again from Triassic to Holocene times. On its eastern side, Catoctin flows initiated a complicated Early Paleozoic eugeosyncline, but from its beginning, this basin received well-sorted and stratified quartzites, limestones, and shales which may be traced to very considerable distances, and which do not resemble Lower Cambrian clastics such as the Chilhowee on the west side of the Blue Ridge. Basic Catoctin flows and intrusions continued during the early stages of their deposition. The primary source of these sediments was probably from a land mass far to the east of the western Piedmont although there were probably local sources of sediment within the geosyncline, and minor uplifts from the western Blue Ridge area produced at times poorly-classified and unsorted deposits. These volcanics and sediments were metamorphosed, folded and overthrust against the Precambrian Blue Ridge massiff at times during the Paleozoic.

The Blue Ridge was again uplifted and downfaulted along its eastern side in the Triassic, and this normal faulting not rec-

ognized by Brown (1958, plate 1, etc.) affords a convenient boundary between that province and the Piedmont of northern and central Virginia (Jonas, Anna I., 1927, Fig. 1, p. 839). The extensive basins of Triassic deposition along this trend from Maryland to central Virginia cover and conceal much western Piedmont geology and disguise its relations to that part of the Piedmont province which remains exposed.

ACKNOWLEDGMENTS

John Rodgers read the preliminary manuscript and made helpful suggestions and criticisms. In the latter part of April, 1968, the writer and James W. Smith visited critical areas in Fredrick County, Maryland, and in the northern and central Blue Ridge province of Virginia. Sericite in specimens of Swift Run tuff from Swift Run Gap and Charlottesville in Albemarle County were identified with X-ray diffraction by James W. Smith. Because unusual circumstances make our own equipment not available for use, the writer wishes to express appreciation of the privilege of our using similar X-ray diffraction facilities in the laboratories of Georgia State. Isotopic age dates upon Lynchburg gneiss specimens from Halfway, Mechum River, and Charlottesville, Virginia, were determined by J. M. Wampler in the laboratories of Charles Weaver, Director of the Geophysical Science Group of the School of Ceramic Engineering, Georgia Institute of Technology. Chemical analyses of Swift Run phyllite or metatuff were made by J. Roger Landrum. James W. Smith critically read the final manuscript and made useful comments.

PURPOSE OF THE DISCUSSION

This paper is written to describe the erosional and depositional sequences of the Late Precambrian as indicated by observations in northern and central Virginia where there are better keys to geologic age and structure than are present in North Georgia. Also, although the two areas are far apart for correlation, Late Precambrian rocks very similar to those of Virginia occur in Murray County, Georgia, directly over earlier Precambrian Fort Mountain Gneiss (Furcron and Teague, 1947, p. 9-14), and they are covered to the east by rocks of the Murphy syncline which are probably Paleozoic in age. Rocks of the Murphy belt exhibit later, probably Paleozoic, metamorphism. These Late Precambrian rocks of Georgia constitute a sequence resembling in stratigraphic position, composition, and grade of metamorphism those of the Lynchburg Group of Virginia.

Precambrian and Paleozoic metasediments are more difficult to separate in Georgia than in Virginia by pure geological methods. Greater use of isotopic determinations for absolute ages and the recognition of metamorphic isograds (Smith, Wampler and Green, 1968), are much needed in Georgia for the establishment of a geologic column of the intrusions and metasediments. Such work will lead to the preparation of a better geologic map for northern areas of the State.

REVIEW OF THE PROBLEM

Blue Ridge, Catoctin Mountain, and the western Piedmont of Virginia between them, are recognized as the Blue Ridge province. The Catoctin Mountain rocks and the Paleozoic sequence west of Blue Ridge are unrelated geographically in Virginia, but evidence indicates that they are related in that both initiate early Paleozoic basins of deposition and rest upon a Late Precambrian unconformity.

Following is a breakdown summary of views expressed in the principal papers upon the areas mentioned above which deal with the entire region or parts of it. Practically all of the writers have made valuable contributions but some have made, or else have retained, errors from earlier writers and some have continuously revised former opinions. Thus, the literature is rather confused and discussions are conflicting. Studies published upon this district range from 1882 to the present and are related to five more or less distinct periods of individual or mass opinion and geologic approach.

Campbell (1882) published independently a book involving the structure, lithology, and formations of the James River Valley. This book was much ahead of the times. He especially studied the district because of the short-lived iron boom from 1879-1882. Campbell established a sequence of limestone over quartzite. He believed what he saw, had no refined techniques, and depended upon lithology. He made no geologic map, probably because there was no suitable planimetric map for the purpose.

Keith (1894a) published upon the entire district from southern Pennsylvania to middle Fauquier and Rappahannock Counties, Virginia, establishing the Triassic basins, the Catoctin Schist and

Loudoun Formation. This is a thorough and outstanding report, but workers who have retained his various opinions upon the "Loudoun" Formation have eventually discarded them.

Furcron, as a graduate student selecting the geology of James River Valley in central Virginia for a thesis, began work in 1925 which continued during most summers between 1926-29. At that time no significant attempt had been made to map metasediments in Virginia. Furcron established a greenstone-quartzite-marble sequence. At the same time, Jonas carried the Maryland sequence east of Catoctin Mountain into central Virginia doing work upon crystalline rocks of Virginia for the new state geologic map published in 1928. At about this time, Furcron discovered Campbell's book which had become obscure and noted the similarity between the conclusions and the opinions reached independently by Jonas. Numerous sections made by working outcrops established lithologic sequences similar to that of Campbell and Jonas. Strong northeast-southwest normal faults and many cross faults follow the Triassic uparched and downfaulted trend with numerous separate remnant basins of Triassic rocks extending into the district. Results of this work by Furcron (with a geologic map) were published in 1935. Later Furcron (1939) published upon the geology of the Warrenton quadrangle and placed the upper part of the Lynchburg Gneiss under Catoctin Mountain volcanic rocks as the Fauquier Formation. His incomplete mapping of the Shenandoah National Park area between Fort Royal and Jarman Gap west of Charlottesville, was placed in open files by the Virginia Geological Survey in 1940.

Brown worked in the field upon the geology of the Lynchburg quadrangle summers of 1940, 1941, 1946, and 1947, for the Virginia Geological Survey. He published on the area (1941, p. 215; 1951, p. 346-347; 1953, p. 88-111) and many of his views were accepted by others before his final report (1958, 99 p., with geologic map) was published. He used the general sequence mentioned above, but from an intepretation of local evidence reversed it. Also, he supplanted the term Wissahickon with Candler Formation. In addition to schist occurring with the marble and Mount Athos quartzite formation he added two additional schist formations. There is Catoctin greenstone on the bottom of the column and a similar one (Slippery Creek) at the top. Marble occurs at several horizons. All of the faults are not-important overthrusts. His geologic column and structural interpretation are sufficiently flexible to meet almost any field condition. However, he begins with Lynchburg gneiss and overlying Catoctin leading eastward into a simple synclinorium. Thus, the same formations must reappear in the Piedmont on the east limb of the synclinorium east of Lynchburg. Here the west limb lithology is ignored, Wissahickon greenstones are called Catoctin, and Wissahickon schist and gneiss become Lynchburg Gneiss. In this district, random and unselected dips on bedding do not justify the synclinorial interpretation.

In 1963 the Southeastern Section of the Geological Society of America met at the Virginia Polytechnic Institute at Blacksburg and their Department of Geological Sciences conducted a field trip into the Altavista area nearby where J. A. Redden (in Weinburg, et al., 1963) has mapped these controversial rocks, but his work is, as yet, unpublished. However, the guidebook gives brief summaries of his conclusions which support determinations as to sequence, structure, and order of deposition generally similar to those of Furcron. Because copies of this guidebook are now difficult to obtain, summary statements from it (1963, p. 77-78) are here cited:

> *Problems relating to the stratigraphy and structure of this belt in Virginia are some of the most interesting in the Appalachian Piedmont. On the Geologic Map of Virginia (Virginia Geological Survey, 1928), the belt is shown to be underlain largely by the Wissahickon schist and Cockeysville marble of the Glenarm series. These two units are interpreted to constitute the overthrust block of a major thrust fault which has subsequently been downthrown along its leading edge at the contact with the crystalline core of the Blue Ridge. This thrust was based on Jonas' reconnaissance studies, which were used in compiling the state map and was correlated by her with the Martic thrust in Pennsylvania and Maryland (Jonas, 1929). Later workers (Espenshade, 1954, and Brown, 1958) have interpreted this contact as either a relatively minor thrust fault or a conformable contact.*
>
> *Furcron (1935) subdivided the Wissahickon into several units when he made his reconnaissance study of the mineral deposit of the James River area. Later, Espenshade (1954) and Brown (1951, 1953, 1958) mapped more or less the same area that had been mapped by Furcron but in considerably*

more detail. They concluded that the general stratigraphic sequence proposed by Furcron was reversed. The names of the different stratigraphic units and the favored sequences proposed by each of these workers are shown in Table 1.

In the southwestern part of Espenshade's map of the James River-Roanake River manganese belt, the sequence preferred by Espenshade required a rather complicated series of faults. Espenshade recognized this difficulty by showing alternative cross sections using a reverse sequence and by stating that considerably more work was needed in the area to resolve the structural problems. During parts of the past three years your leader has mapped an area that extends across this belt southwest of the Roanoke River (Pl. 4.1). The results of this mapping suggest that a stratigraphic sequence which is the reverse of that used by Espenshade and Brown is more logical. This sequence is also shown in Table 1. Although the reverse sequence explains and greatly simplifies the geological interpretation of much of the southwestern part of the area mapped by Espenshade, it does not necessarily simplify interpretations for the area east of Lynchburg.

The stratigraphic and structural problems and disagreements are no doubt caused to a great extent by the lack of exposures in the deeply weathered Piedmont. All faults are essentially inferred and have to be based on an incompletely exposed lithologic sequence. Inasmuch as different workers have obtained opposite stratigraphic sequences, there may well be two or more very similar lithologic units which have been at least locally confused.

On the field trip you will be shown some of the evidence for the reverse stratigraphy preferred by your leader in the Altavista area and also variations in lithology caused by increasing metamorphic intensity and local multiple (?) metamorphism.

Again (p. 83-84) referring to Brown (1958) he cites the reasons for normal faulting of the retrogressive Wissahickon and reasons against a gradational contact between "Evington" and Lynchburg.

Faults are based entirely on the general map pattern and considerations of the lithologic sequence. A sizable thrust fault is inferred to have involved thrusting of the Mount Athos *formation over part of the Old Woman Creek syncline in the southeastern part of the area. However, the Hundley dome has effectively warped this fault at some later time. Another thrust fault borders the west side of the Johnson dome but its trace is only approximately located along the west side of the King George anticline.*

The so-called "Martic Line" or the contact between the Evington group and older rocks to the west is, according to the present stratigraphy, a normal fault downthrown on the east side. Jonas' (1928) interpretation was that a normal fault had downthrown the thrust plane. However, as previously mentioned, more recent workers have interpreted the evidence otherwise: Brown (1958) indicates a normal depositional contact, at least locally; Espenshade's map shows a thrust fault contact but he indicates in his text that he does not believe it to be an exceptionally large fault. Espenshade shows greenstone to occur locally, northwest of the contact, more or less as is shown in Pl. 4.1. This suggests a fault contact even though Brown (1958) states that the contact between the two units is gradational. In the Altavista area, although the actual contact is nowhere exposed, the general topographic expression at the approximate contact suggests that the contact has at least a 60° dip to the southeast. Locally there are a few beds directly above the greenstone which resemble Lynchburg in the dome areas to the southeast. However, nothing in the Candler appears to grade into the Lynchburg along the northwestern part of the area.

Unless an unconformity does exist, there must be a fault along this contact because locally Candler is in contact with greenstone and elsewhere with Lynchburg. If the contact is not a fault it is necessary to infer either 1, that Brown's and Espenshade's sequence is correct and inverted younger rocks (Archer Creek and Mount Athos) have been thrust over most of the area shown in Pl. 4.1, or 2, that an unconformity exists above the Candler in the central and eastern parts of the area. Further, if the unconformity existed, the Mount Athos would be still older than the Archer Creek. Also, there are no places in the central and southeastern part of the area where Candler is preserved below the Mount Athos. The same general type of objection holds if an unconformity should exist below the Candler.

Additional evidence favoring the interpretation involving a normal fault is the relative straightness of the contact for nearly 100 miles — from the northeastern end of Espenshade's map to Chestnut Mountain, southeast of the Altavista area. A normal fault, downthrown on the southeast is also logical in that several downfaulted Triassic basins occur in this same belt of metamorphic rocks near the James River and the entire belt is covered by Triassic rocks in northern Virginia. Therefore, this belt is believed to be fundamentally a crustal block which has been downdropped relative to the Catoctin-Blue Ridge anticlinorium to the northwest.

The metamorphic intensity ranges from upper low grade (biotite) into high grade (sillimanite). Texturally, the pelitic rocks range from phyllites to sillimanite gneisses in which the grain size of biotite grains and sillimanite aggregates is a centimeter or more. Retrograde andulusite-cordierite schists locally contain pseudomorphs after porphyroblasts which were as much as eight inches long.

The mineral isograds trend slightly more easterly than the regional strike. There is thus relatively little change in metamorphic intensity along strike but much change across strike. The width of the staurolite zone for example ranges from one to two miles. Several minerals in each zone have been retrograded to lower (?) intensity minerals.

The lowest grade rocks occur in a narrow belt that extends through Leesville where the pelitic rocks have various combinations of the minerals chlorite, chloritoid, muscovite, paragonite, biotite, albite, microcline, and quartz. Each assemblage appears to be in equilibrium and to conform to limitations of the phase rule.

There is a gradual increase in grain size in going from the biotite through the garnet zone to the staurolite zone. Garnet and staurolite occur as porphyroblasts in the darker beds which were initially rich in chlorite. In many of the muscovite-rich schist beds in the Mount Athos, there is little change in texture and garnet and staurolite do not appear. Apparently the staurolite formed largely at the expense of chlorite inasmuch as chloritoid persists in some samples. Andulusite and cordierite apparently occurred in the staurolite zone in the two thin stra-

tigraphic units. However, both minerals have been retrograded to micaeous minerals in all of the known exposures of the units.

This paper is not intended to discuss Brown's James River synclinorium at length but some consideration has been necessary because it is a required feature as part of the Blue Ridge anticlinorium of Bloomer.

James W. Smith has called the writer's attention to a recent publication (Ern, 1968, p. 30-32, Pl. 1) where Brown's James River Synclinorium is recognized in the text but can not be confirmed by his structural symbols or cross-sections.

During the recent period from 1958 to present, not much interest has centered in Blue Ridge problems. Several theses have been published. Also, the Virginia Geological Survey has published county reports by Nelson (1962, 92 p.) and by Allen (1963, 102 p.; 1967, 78 p.) all with very helpful geologic maps. Very little has been published upon the eastern Catoctin Mountain belt and the Piedmont east of it. The Maryland Geological Survey has a new geologic map of the state in press. Hopson (1964) published a thorough study of the Glenarm Series of Howard and Montgomery Counties, Maryland.

Stose and Stose, working independently in the Blue Ridge, established the Swift Run Tuff (1944) between the igneous complex and the Blue Ridge greenstone. Nelson called attention to the Rockfish Conglomerate (1932, p. 456-457). Jonas and Stose described this conglomerate (1939, p. 575, 578, 579, 593) as basal Lynchburg. Also during this period papers were published by Bloomer and Bloomer; Bloomer; and Bloomer and Werner.

Stose and Stose (1946) indicate the Catoctin surrounds and connects Catoctin and South Mountains where the earlier Precambrian plunges northeastward under it in Frederick County, Maryland.

BLUE RIDGE ANTICLINORIUM

Jonas (1927, p. 840-841) described a large positive, structural region in northern and central Virginia as the "Catoctin-Blue Ridge anticlinorium" and its definitive character has been substantiated by later work. There have been no arguments opposed to its existence.

However, during the last thirty years some writers cited in this paper would lead us to believe that upon a large regional basis this anticlinorium is resolved by establishing a synclinorium in the Piedmont of northern and central Virginia which leads into an anticlinorium in the Blue Ridge region; that formations are correlative into and over both major structures, and that no significant erosion intervals interrupt continuous deposition even over the anticlinorium, from the unconformity above earlier Precambrian into (how far never indicated) the Paleozoic sequence of the Valley and Ridge province west of the Blue Ridge. Figure 2, this paper, offers a reconstruction of the depositional, erosional, and structural history of the region.

Bloomer and Bloomer (1947, p. 94-106) describe the Oronoco Formation which they acknowledge is Swift Run, the Blue Ridge "Catoctin" and the Unicoi as a continuous stratigraphic series; they believe the Lynchburg and Oronoco may be the same thus all may be Cambrian.

Bloomer (1950, p. 753-783, fig. 5) projects Brown's synclinorium (fig. 1) westward over the Blue Ridge "anticlinorium" to correlate Lynchburg with Swift Run and the eastern "Catoctin" and overlying Wissahickon (?) with the Blue Ridge "Catoctin". He places the Swift Run and Lynchburg in Late Precambrian and the Blue Ridge-Catoctin in continuous sequence from the base of the Lynchburg into the Lower Cambrian. He writes (1950, p. 753) "In places there appears to be a complete section between the Catoctin in the Blue Ridge and the Wissahickon in the Piedmont of central Virginia." Bloomer and Werner (1955, p. 579) conclude that ". . . . there is an uninterrupted sequence of formations above the early Precambrian basement complex and . . . . the Precambrian formations of the Piedmont are conformably related to the Cambrian formations of the Valley and Ridge."

The Late Precambrian Lynchburg Group is not conformable with Cambrian formations of Valley and Ridge or of the Blue Ridge. Bloomer and Werner (1955, p. 583) correlate these Piedmont rocks with the Lynchburg, but do not make further use of the observation. They continue to correlate the Lynchburg over their Blue Ridge anticlinorium with Swift Run. The eugeosynclinal formations (1955, fig. 4, p. 588) in Brown's synclinorium (Evington group and Wissahickon) they correlate with lower

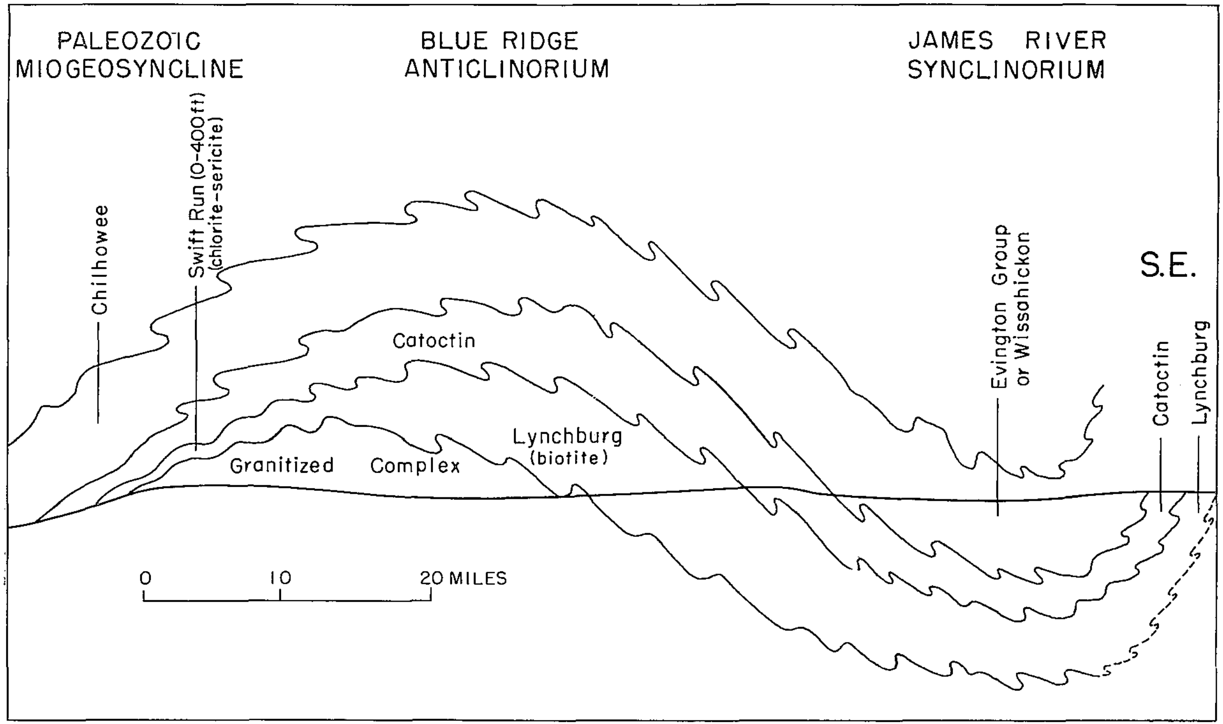

Figure 1—Diagramatic interpretation of Blue Ridge and Western Piedmont of Central Virginia after Bloomer (1950, p. 579-593; Figure 5) and Brown (1958, and Plate V, Sec. C-C'); faults are omitted; original elevation of structures and thickness of formation not known. The only erosion interval recognized by them is over the granitized Early Precambrian Complex.

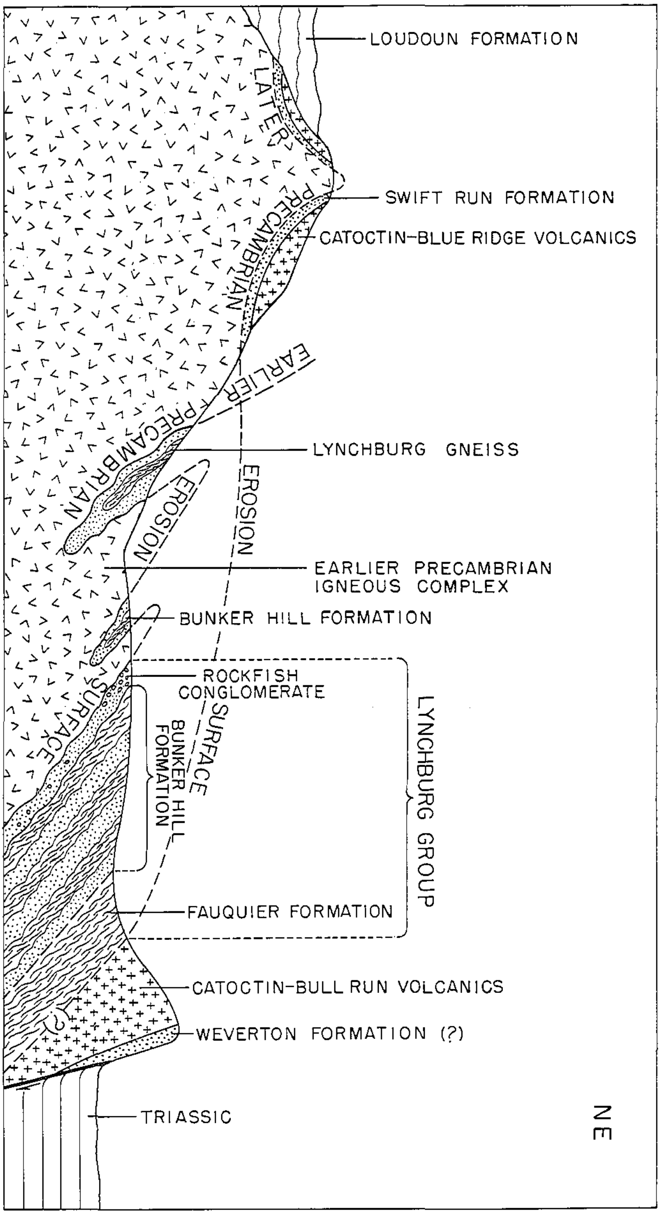

Figure 2—Diagrammatic Section through the Blue Ridge of Northern and Central Virginia illustrating depositional and erosional sequences.

Chilhowee formations of the miogeosyncline. These formations cannot be correlated from east to west as they suggest.

LYNCHBURG GROUP

The Lynchburg Gneiss was described by Jonas (1927, p. 845) as within the Catoctin-Blue Ridge anticlinorium with its type locality at Lynchburg. Later (Stose and Stose, 1944, p. 367), it was found to be younger than the earlier Precambrian or injection complex and believed to be equivalent to a Late Precambrian group.

In central and northern Virginia Lynchburg Gneiss occurs over the earlier Precambrian on the eastern side of the Blue Ridge province and under Catoctin Greenstone volcanic rocks. It consists of metasedimentary biotite garnet gneiss and schist, biotite quartzite and arkose, and dark to light gray slates dipping southeastward. The rock types are difficult to separate into formations.

In this paper Lynchburg Gneiss is divided into two lithologic sequences to form the Lynchburg Group. The upper part of the group directly under Catoctin is referred to as the Fauquier Formation (Furcron, 1939). The lower part of the group, composed of arkose, biotite arkose, and dark and gray slates, is here defined as the Bunker Hill Formation. The Fauquier Formation is absent locally and especially in northern Fauquier and Loudoun counties.

The Lynchburg Group has an angular unconformity beneath and over it, thus Late Precambrian is merely a relative and not too desirable age designation. It is much older than Paleozoic. Dietrich et al. (1967, table II) find that in southwestern Virginia "Lynchburg" Formation appears to have been last metamorphosed in the Precambrian, 620-825 million years ago.

Long, Kulp, and Eckelmann (1959) using K—Ar determinations have found that rocks which are here classified as Late Precambrian range generally circa 350 million years, the period when they were last reheated. At least some of the Precambrian gives ages of circa a billion years.

Woodward (1957, p. 2312-2327) states that most Cambrian clastics were derived from an eastern Appalachian highland. In referring to its western miogeosyncline he states (p. 2312) that "the eastern highlands were essentially destroyed by erosion before the middle of the Cambrian, and Cambro-Ordovician carbonate rocks testify to a continental shelf site of deposit instead of a geosynclinal site as is commonly assumed." Unconformity and renewal of clastic deposition in the miogeosyncline also indicate some stress pressure from the east which may have accompanied revived regional uplift.

The Lynchburg Group is derived from the Early Precambrian surface but was mostly eroded away before the western Lower Cambrian sea invaded the Blue Ridge area in this region. The Lynchburg extended eastward over the Piedmont for an unknown distance but is thick on the east side of the present Blue Ridge province and under the western Paleozoic piedmont metasediments. It was warped down in Early Cambrian times by Catoctin flows which initiated a complex Paleozoic eugeosyncline over much of the western Piedmont.

The K-Ar determinations upon Lynchburg gneisses appear neither to confirm their geologic age nor period of highest metamorphic grade (Table 1). Have unrecorded temperature-stress conditions which have not changed the physical appearance of the micas served to rejuvenate their isotopes?

Table 1 cites recent K-Ar age determinations upon Lynchburg Gneiss from several other significant localities.

TABLE 1

Age Determinations of Last Period of Heating of Lynchburg Gneisses.

by J. M. Wampler
Georgia Institute of Technology

K-Ar Age million years	Sampled Locality
425 ± 25	One-half mile east of Long Branch Church at Halfway, Fauquier County on Virginia Highway 626; under Catoctin.
410 ± 25	West side of bridge crossing Mechum River, Albemarle County, on Virginia Highway 614.
345 ± 20	Perimeter highway roadcut at intersection of U. S. Highway 29 on south side of Charlottesville, Albemarle County, Virginia; under Swift Run and Catoctin.

Bunker Hill Formation

Lynchburg Gneiss constitutes a major part of the old Loudoun Formation of Keith (1894a, p. 324-329) but only that part of it which he assigned to the Blue Ridge province which lies over the earlier Precambrian basement between the two Catoctin belts of northern Virginia.

Exposures here selected as type localities of its basal member, the Bunker Hill Formation, may be seen in Fauquier County on Virginia Highway 55 (The John Marshall Highway), between Marshall and The Plains, where beds with a steep monoclinal dip to the southeast are especially well exposed on The Glebe and at the old settlement of Bunker Hill. Also, excellent outcrops to the north and northeast are in the vicinity of Zulla and west of Halfway along Goose Creek near Fox Croft school in Loudoun County.

The Warrenton agglomerate member of the Catoctin Mountain volcanic rocks may be seen at the Southern Railway Station and in front of the Rectory in The Plains (Furcron, 1939, p. 20) where it occurs somewhat above the base of the volcanic rocks. Two-tenths mile west of The Plains and just east of the entrance to Glenville, Catoctin greenstone dipping southeast was formerly exposed on the old highway near the base of a slope, and from this locality westward about eight-tenths mile, the Fauquier Formation may occur in lowland but is not exposed. Outcrops of the Bunker Hill Formation extend along the highway from about a mile west of The Plains nearly to Brooks' Corner. The underlying basement complex member of Marshall Granite (Jonas, 1927) is well exposed in Marshall and vicinage.

The Bunker Hill Formation is composed of coarse to medium-grained biotite arkose or arkosic biotite gneiss, interlayered with gray slates. Arkose beds weather to a gray "sandstone" but where fresh they are hard arkosic biotite gneiss. Conglomerates near or at the base are reported locally where they constitute the equivalent of Rockfish Conglomerate. Coarse, angular, milky and blue quartz and potash feldspar are the notable constituents and lower beds may resemble Marshall Granite. Fine grains of quartz and muscovite fill interstices between larger grains. Micas are secondary and more notable in fine-grained gneisses. The entire formation seems to have been deposited rapidly, since crossbedding and effects of current action are not particularly present.

Topography is rolling, and massive arkose beds form ridges. Bunker Hill is situated on several ridges near the base of the formation. Most land over this formation is now in pasture and the rougher sections have always remained in hardwood. Formerly, small dike or sill-like bodies of hornblende gabbro, fine to coarse, were occasionally encountered in cultivated fields. None have been seen in exposures along the road at the type locality, but fragments of them are locally used in the stone fences. Brown (1958) finds abundant hornblende gneiss and amphibolite in the lower part of the Lynchburg gneiss and the underlying basement west of Lynchburg.

The Bunker Hill Formation with a local basal conglomerate (Rockfish Conglomerate) occurs as infolds over the earlier Precambrian basement on the long eastern slopes of the Blue Ridge range. Steeply-dipping outliers may be observed along the John Marshall Highway (Virginia Highway 55) between Marshall and the Blue Ridge greenstone volcanic rocks. Unless local conditions require it, faults are not needed to explain their position. In cross sections, they are portrayed as infolds usually overturned to the northwest.

Northeast of Lynchburg, south of the Southern Railway there is a good section of the Lynchburg Group overlaid to the east by Catoctin Greenstone. The Bunker Hill formation rests upon Lovingston Gneiss and is well exposed south of Amherst, Tye River, and Naked Mountains. This was mapped (Furcron, 1935) as Loudoun. It corresponds to Keith's metasedimentary "Loudoun" of Loudoun County and is not Cambrian.

Fauquier Formation

This formation was recognized by Furcron (1939, p. 37-41) from the area of the Warrenton quadrangle in northern Fauquier County. It was separated from the "Loudoun" and described as under the Catoctin Mountain greenstone. It represents a continuation of Bunker Hill deposition but with changed and varying lithologies and with generally increased susceptibility to intrusion of basic rocks related to the extrusive greenstone volcanic rocks. From northern to central Virginia, these hornblende metagabbro, metapyroxenite, or amphibolite dikes occur in it. There is an unconformity (probably erosional) between this formation and the Catoctin and Swift Run.

Upon the Warrenton quadrangle the formation is composed of fine-grained biotite gneiss beds, mica schist, fine-grained quartz mica schists with biotite porphyroblasts; arkosic gneiss beds; black slates used locally in the past as roofing slates, and crystalline blue, pink, and white marble. The black slate facies was mapped separately upon the Warrenton quadrangle.

The Fauqier Formation comprises the upper part of the Lynchburg Group from northern to central Virginia. In Albemarle County, it is exposed in a belt four to six miles wide. Upon the Warrenton quadrangle it appears to be equally well deposited, but, as in most localities, it is much affected by normal faults probably of Triassic age. North of Warrenton, outcrops of the formation become thinner and less well exposed. Northeast of The Plains, the Bunker Hill Formation crops out close to the west side of Bull Run Mountain suggesting the possibility that the Fauquier Formation is thin or more covered by Catoctin or possibly eroded after Swift Run times.

Southwest of Culpepper County, Allen (1963, p. 25-31, geologic map) mapped a wide belt of Lynchburg Gneiss in the eastern half of Madison and Greene Counties. He notes (p. 26) that this gneiss is lithologically similar in part to the Fauquier Formation. It is consistently intruded by amphibolite and ultramafics.

In Albemarle County (Nelson, 1962, p. 21-22, geologic map) the Charlottesville Formation is the Fauquier Formation and the Johnson Mill Formation corresponds to the dark slate facies. Furcron (1935, p. 41) writes of the Fauquier Formation: "The graphitic schists and associated amphibolite rocks of the University quadrangle are probably a southwestward continuation of this belt of Precambrian rocks."

Marble:

On the east side of the Catoctin Greenstone belt and over it, Jonas mapped Everona Limestone of Ordovician age upon the Geologic Map of Virginia (Virginia Geological Survey, 1928). In Fauquier and Loudoun there is marble cropping out in a long line above the Fauquier Formation and dipping under the greenstone. Both occurrences are considered to be Everona by Mack (1965) but it is the blue slaty limestone east of the Catoctin that Miss Jonas considered as Everona. However, his accurate descriptions show the Everona to be characteristically a blue slaty limestone over Catoctin Greenstone, but northeast of Rappahannock River in Fauquier and Loudoun Counties, it is a coarsely crystalline white marble generally dipping under greenstone but closely related to it, and of older age.

SWIFT RUN FORMATION

The Swift Run Formation (Swift Run Tuff, Stose and Stose, 1944, p. 410) supplants the Oronoco Formation (Bloomer and Bloomer, 1947, p. 94, 95) and has for its type locality the east side of Swift Run Gap, U. S. Highway 33 in the Blue Ridge southeast of Elkton, Virginia, where it is described as tuffaceous arkosic sediments overlying the injection complex and underlying the Blue Ridge Catoctin volcanic rocks. When U. S. Highway 33 was reconstructed and straightened, access to much of the original outcrop was made difficult. However, from the entrance to the Skyline Drive there are good exposures eastward from the gap of sericitic phyllite believed to be metatuff. Exposures from near Whitehall, Albemarle County, up Sugar Hollow are nearby and make a good substitute for the type locality.

The Swift Run is the result of explosive volcanic activity which preceded the eruption of Catoctin, and these volcanics, where checked, are generally more acid than Catoctin flows and their accompanying intrusions and are of near surface origin (table 2). In Sugar Hollow green chloritic phyllites are typical and there is much small fragmented basement granodiorite (arkose) which contained enough ash to become cemented with a chlorite matrix. Vokes (1957, p. 43, 72) refers to Swift Run in Maryland as the tuff member of the Catoctin metavolcanic rocks. However, green chlorite schist at or near the base of the Catoctin, as west of Middletown, Maryland, on U. S. Highway 40, may be found at almost any Catoctin locality and belongs to Catoctin rather than Swift Run. Some prefer to include lower Catoctin flows and interbedded arkose with Swift Run. The top of Swift Run and the base of Catoctin may be difficult to establish in some localities. In Charlottesville, sericite tuff under Catoctin underlain by a tuffaceous arkose composed of fragmented Lynchburg over Lynchburg Gneiss establishes it as a definite formation.

Since the Swift Run was described (Stose and Stose, 1944, p. 410) it has been miscorrelated with Lynchburg gneiss, a high grade metamorphic sediment which underlies it. Obviously, Swift Run overlies Lynchburg as for example in Charlottesville. West-

TABLE 2

Chemical Analyses of Swift Run Formation Phyllites and Mechum River Phyllite

by J. Roger Landrum

	Swift Run Formation type locality (on Blue Ridge Parkway just east of Swift Run Gap)	Swift Run Formation, Charlottesville, U. S. Hwy. 250 at Marshall Street	Mechum River phyllite U. S. Hwy. 250 at town of Mechum River
Loss on ignition	4.53%	4.32%	4.63%
Na_2O	0.50%	0.44%	0.76%
K_2O	4.49%	5.06%	6.46%
CaO	0.14%	0.62%	0.30%
MgO	1.22%	1.38%	1.84%
Al_2O_3	31.60%	21.00%	19.00%
Fe_2O_3	6.72%	8.97%	3.68%
FeO	1.16%	0.86%	6.20%
MnO	0.01%	0.06%	0.13%
TiO_2	2.40%	0.60%	0.60%
SO_3	0.05%	0.03%	0.06%
P_2O_5	0.11%	0.13%	0.25%
SiO_2	47.12%	56.62%	56.34%
TOTAL	100.05%	100.09%	100.25%

ward, where Lynchburg was removed by erosion or not deposited it does overlie Early Precambrian basement, but it is volcanic and does not "overlap" Lynchburg from east to west as some state (Bloomer and Werner, 1955, p. 587). It may overlie Lynchburg gneiss wherever that formation remained prior to Swift Run times.

Swift Run (as the Catoctin) is characterized by a progressive low grade metamorphism of Paleozoic age. These green schist formations cannot be correlated mineralwise with the biotite gneiss of the Lynchburg Group. At present, Swift Run is defined more by its stratigraphic position than by its metamorphic grade and composition. We do not know how far westward Lynchburg infolds into igneous basement occur. Lynchburg Gneiss is also between basement and Catoctin and both formations dip southeast, but Lynchburg contains biotite and has not been seen to contain volcanic rocks. Bloomer (1950, p. 753-783, fig. 4) correlates Swift Run over the Blue Ridge anticlinorium to include Lynchburg Gneiss and Catoctin-Wissahickon rocks of the Piedmont east of the Blue Ridge province (fig. 1). This writer (fig. 2) does not believe that stratigraphic, structural, and metamorphic conditions confirm Bloomer's theory.

Swift Run is thick under both Blue Ridge and the eastern Catoctin belt in central Virginia. Nelson (1962, p. 22-24, geologic map) records thickness up to 2,600 feet in Albemarle County and his geologic map indicates prominent outliers of Swift Run in the Blue Ridge range which are capped by Catoctin. In the Blue Ridge, Swift Run is spotty and deposited on a surface of considerable relief. The formation is thin or absent in the Blue Ridge of northern Virginia, and scarce or absent also under the Bull Run Catoctin trend in northern Virginia.

The arkose, slate, biotite gneiss and biotite-bearing arkose beds with overlying marble which here are classified with the Lynchburg Group, have recently (Parker, 1968, p. 7-13) been described in Loudoun County as Swift Run. These rocks are not pyroclastic or volcanic, nor are they similar to those of the type locality in Green County or to the many classic exposures of Swift Run in Albemarle County.

MECHUM RIVER

The Mechum River metasedimentary rocks are described (Gooch, 1958, p. 569-574) as a belt of rocks about 60 miles long and one-half to two miles wide in Albemarle, Greene, Culpeper, and Rappahannock Counties in the middle part of the Blue Ridge province and about midway between Lynchburg Gneiss and Swift Run. It is infolded into the Precambrian igneous basement, and its members dip steeply southeastward. It is explained (p. 573, fig. 2) as part Lynchburg and part Swift Run. The distinction between the two is not clearly defined.

Allen (1963, p. 32-33, geologic map) describes Mechum River from Madison and Greene Counties as lithologically similar to Lynchburg and (p. 11) suggests age and lithologic equivalence of Swift Run, Mechum River, and Lynchburg.

The units described as Mechum River need mapping upon a larger scale with view to re-interpretation. At Mechum River

Station, a green chloritic phyllite dips steeply southeast where it is bounded by biotite-bearing igneous rocks. At the crossing of U. S. Highway 250 on the west side of Mechum River, biotite Lynchburg gneiss occurs. Evidence indicates that we have two types of rocks in this belt of differing lithology and origin, and that they are metamorphosed progressively to two different grades at different geologic periods. The Lynchburg Gneiss represents progressive metamorphism to the biotite-garnet grade, but the green phyllite was arrested in the chlorite stage. It is here suggested that the Lynchburg was folded, metamorphosed, and eroded, and that later Swift Run was deposited, metamorphosed, and infolded with Lynchburg during the Paleozoic.

CATOCTIN GREENSTONE VOLCANICS

Eastern Catoctin Belt

Keith (1894a, p. 306-318, geologic map) defines Catoctin Schist in Pennsylvania, Maryland, and northern Virginia and regarded the eastern Catoctin Mountain-Bull Run belt as of the same age as similar volcanic rocks in the Virginia Blue Ridge. This view has been maintained by later geologists. The eastern belt in Virginia is over Swift Run and/or the Lynchburg Group. Over the greenstone, Toewe (1966, p. 4-5, geologic map) maps as Weverton a white granular quartzite which dips steeply southeast. This quartzite is well exposed over greenstone on and east of High Point at Beverly's Mill northeast of The Plains in Fauquier County. The writer has observed thin beds of white quartzite in upper Catoctin exposed along the old Warrenton-The Plains road. Muscovite schists and quartzite overlie the basal quartzite bed northeast of Warrenton.

The entire sequence following the basal quartzite is downfaulted and covered by Triassic rocks in a basin which extends southward from Maryland to Rapidan River in north-central Virginia.

The Catoctin volcanic activity initiated as a series of flows and early Paleozoic metamorphosed sediments which Jonas (1927, p. 837-846; 1928) regards as a southwestern extension of Wissahickon Schist and underlying volcanic rocks, marbles, and quartzite of Maryland. Agglomerate, pyroclastics, and chlorite schist compose a larger percentage of the eastern Catoctin than of the Blue Ridge volcanic rocks. Also, the flows continued throughout the quartzite, marble, and schist sequence east of Bull Run Mountain and others of its southwest extension.

Recent workers (Herz, 1951, p. 980; Choquette, 1960, p. 1029) recognize the sequence established by Jonas as early Paleozoic.

Blue Ridge Catoctin Belt

The Swift Run Formation and Blue Ridge greenstone volcanic rocks overlie the granodiorite and injection gneiss of Precambrian age. Volcanic agglomerate common to the eastern volcanic belt (Furcron, 1935, p. 20-22, pl. 5) is rare and extremely local. Narrow greenstone dikes intrude the basement occasionally and have been termed "feeder dikes". They are scarce and narrow and seem to represent tension joints filled with lava. By some (Bloomer and Bloomer, 1947, p. 100) they are assumed to be the source of the Catoctin flows.

King (1950, p. 13-14) calls attention to the thinning out of the Blue Ridge greenstone westward in the Blue Ridge and a possibility that flows may have come from the east. The gradient of the Late Precambrian erosion surface is not known but it seems likely that it was warped downward as the Catoctin flows and later flows and sediments were deposited. Catoctin flows extend into the east Paleozoic basin, thus may have been poured out more extensively there in its declining stages during the Early Paleozoic than it was in the Blue Ridge belt.

Extensive metapyroxenite and soapstone intrusions which are associated with the Catoctin belt do not occur in any important way in this section of the Blue Ridge.

It may be significant that both belts thin out under erosion southwestward in middle Virginia. Vulcanism may have begun with Swift Run Pyroclastics and progressed northeastward in the case of both trends.

In the southwest Virginia Blue Ridge, Stose and Stose (1957, p. 1-233, pl. 57, geologic map) have described the Mount Rogers volcanic group. Their thorough lithologic and structural descriptions and detailed geologic map make this work an outstanding contribution to a difficult section of Appalachian geology. South of Wytheville, Unicoi with greenstone flows overlies earlier Precambrian and the Mount Rogers volcanic group which also overlies earlier Precambrian. This group is not metamorphosed and on the legend of the geologic map occupies the same position as the Blue Ridge greenstone volcanics and Swift Run to the northeast. The Gossan Lead overthrust separates it and its earlier Precambrian basement from the Lynchburg Group. Diabase and rhyolite dikes which cross cut the lower Unicoi Formation are shown in their figure 12, page 60. Jonas and Stose (1938, p. 575-593) correlate the Mount Rogers volcanic rocks with the Blue Ridge greenstone volcanic rocks to the northeast. It appears that the thickened Chilhowee sequence below the Unicoi to the southwest may occupy an interval, a portion of which is taken up farther northeast in Virginia by the Mount Rogers volcanic group, the Blue Ridge greenstone volcanic rocks, and the Swift Run.

LOUDOUN FORMATION

Well exposed on the western side of the Blue Ridge (Nelson, 1962; Allen, 1963, 1967; Furcron, 1940), unconformable over the earlier Precambrian complex and Blue Ridge greenstone volcanic rocks, this formation is the last remaining portion of the old Loudoun Formation (Keith, 1894a, p. 285-395) to bear its name. Woodward (1949, p. 67-69) states that the term, Loudoun, has caused confusion. King (1950, p. 16-17) is dissatisfied with the term and doubts if it is a valid unit where studied in the Elkton area. Because the original term includes three different rock sequences, at least two of which are of very different geological ages, the term does not accord with the definition of a formation. This has caused long-standing misinterpretation of geologic age and structures, thus its continued use is undesirable.

Interest in the formation as currently defined centers around the evidence which it may offer for or against an unconformity at its base. In central Virginia, Bloomer and Bloomer (1947, p. 106) believe that evidence indicates no unconformity between Lower Cambrian and the Blue Ridge greenstone volcanic rocks. Bloomer and Werner (1955, p. 594-595) offer detailed local lithological evidence for this belief including tuff, some greenstone, and basalt flows. Bloomer (1950, p. 775) gives evidence to prove that eruptions of Blue Ridge volcanic material died out in Loudoun times. Volcanic rocks at the base of the Loudoun near Port Republic (Furcron and Woodward, 1936, p. 400-410) should be of Loudoun age but are at the base. In the northern Blue Ridge where Catoctin volcanic rocks are under Loudoun, descriptions of those within the Loudoun are too general. Some of the importance of this unconformity depends upon a re-examination of the volcanic material so that observations may be brought into accord. An examination of literature on northern Virginia indicates the presence of green spotted slates, purple and red slates and phyllites, sericite phyllites probably representing volcanic tuffs, and also lava flows in some localities not cited. The presence of pyroclastics and flows into Lower Cambrian clastics weaken the importance of unconformity. However, in the Blue Ridge, vulcanism begins with pyroclastics, lava flows, and sediments of the Swift Run and pyroclastics continued into the overlapping Loudoun sediments after Catoctin times leaving a definite sedimentary unconformity at their base. In the Elkton area King (1950, p. 13-14) accepts the volcanic rocks as flows but offers evidence for a definite unconformity. Other reasons for some unconformity are given in the concluding section of this paper.

EROSIONAL HISTORY

Three significant unconformities are recognized in northern and central Virginia. With no paleontological evidence their importance in time is a matter of opinion based upon evaluation of the observed evidence that is considered.

The earlier Precambrian rocks known as the Virginia Blue Ridge igneous complex, composed of migmatites, granodiorite, and granites is under a great unconformity in the Blue Ridge and Piedmont to the east. It is overlain in that region by the Lynchburg Group of Late Precambrian age which is dipping steeply southeast and locally sheared or overthrust from the eastern side. These outcrops thin out to infolds with northeast-southwest trends east of the Blue Ridge summit. The source material of Late Precambrian rocks came from the old basement underneath and also from rocks farther west. Its thinning out westward indicates a long period of erosion at the close of the Precambrian and probably more rapid erosion in the Blue Ridge. The group was thinner also in the Blue Ridge where the Rockfish conglomerate is less localized. Probably much western Precambrian highland, subject to erosion in Late Precambrian times, is now beneath the miogeosyncline of the Valley and Ridge province.

During pre-Paleozoic times, the Late Precambrian was folded and eroded in the Blue Ridge and Piedmont down to the old complex, especially in the Blue Ridge and its long hilly eastern slopes. Its folding and erosion are pre-Swift Run. Swift Run and Blue Ridge greenstone, although varying in thickness with terrane, are deposited unconformably and horizontally over it and the older basement but later folded during the Paleozoic. The post-Lynchburg erosion surface merges with that of the old basement complex beneath the Swift Run in the Blue Ridge. Only where covered does it remain, at elevations of 2,000 - 3,000 feet near the Blue Ridge summit. It may be warped downward on the west side of the Blue Ridge. In the Piedmont it may be preserved but downwarped under Swift Run or Catoctin greenstone. This hiatus is believed to be second in time value to that over the Precambrian igneous complex.

The third unconformity is observed on the western flanks of the Blue Ridge and from its crest on the western side down to the Loudoun or the Unicoi formations, the first exposed formations deposited by advancing Chilhowee seas. There are differences of opinion concerning its value. The following view by Bloomer, Werner and Brown are believed by Furcron to be unjustified by geological evidence presented in this paper.

Bloomer (1950, p. 769, fig. 5) and Bloomer and Werner (1955, p. 584, fig. 1) do not recognize these erosion periods. They regard the Swift Run as Upper Lynchburg Gneiss and the "Catoctin" of the Blue Ridge to be conformably overlain by Lower Cambrian Unicoi but no significant unconformities. They regard Late Precambrian rocks and overlying Swift Run and Catoctin to be in normal sequence east and west of the old igneous complex from the axis of the Blue Ridge anticlinorium (fig. 1). This regional concept is an expansion of Brown's synclinorium (1958, p. 99, geologic map) comprised of the Evington Group over Catoctin volcanic rocks and basal Lynchburg Gneiss, all in sequence east of the Blue Ridge anticlinorium. Bloomer and Werner (1955, p. 600, paragraph 6) write of the Catoctin Mountain-Blue Ridge anticlinorium: "The southeastern limb is defined by the axis of the James River synclinorium (Brown, 1953, p. 92-94) and contains the Lynchburg formation, Catoctin greenstone, and Evington group." Thus the Evington Group is believed to extend westward over the anticlinorium with the Chilhowee as its western equivalent (Bloomer and Werner, 1955, p. 599).

King (1950, p. 14) cites reasons for believing that an unconformity exists at the base of the Loudoun at least in the Elkton area.

The Loudoun or Unicoi-Precambrian hiatus where observed in this paper is regarded as relatively minor. Much of the erosion observed down to the Blue Ridge complex took place during the first two erosion periods. King concluded that in the Elkton area evidence indicates the Swift Run and Catoctin are Precambrian and dissimilar from the Chilhowee Group. This writer believes they are dissimilar because they are volcanic and that the scales tip the other way, thus the unconformity by overlap is not sufficient to assign these volcanic rocks, even in the Elkton area, to a Precambrian age because there is volcanic conformity across the Loudoun-greenstone unconformity. Cloos (1951, p. 27) gives reasons for believing that the Catoctin may be Cambrian. An angular unconformity under Swift Run and the Blue Ridge volcanic rocks argues against placing these volcanic rocks and associated sediments with the Lynchburg Group or the Ocoee supergroup. Their low grade metamorphism is another deterrent. Thus they seem to constitute a volcanic group beneath the Chilhowee Group separated from it by unconformity but closely allied to it in age.

This third erosion period is recognized as a composite unconformity wherein the earlier Precambrian erosion cycle merges with that of the Late Precambrian under the Swift Run-greenstone volcanic rocks of the Blue Ridge, and under Loudoun Formation. Also, merging with them is a much lesser break between the Loudoun and the Blue Ridge greenstone volcanic rocks.

Thus, a major consideration for the third unconformity is the fact that the Loudoun or Unicoi sea encroached upon earlier Precambrian rocks beneath an erosion surface produced by the merging of two great Precambrian erosion periods. But this merging of erosion periods is also under Swift Run and greenstone volcanic rocks; thus, because these formations are also on Catoctin rocks, this erosion period is small because it appears to have required only a short time for the deposition of the volcanic rocks and for their erosion—a condition also evinced by continued vulcanism into the Loudoun and Unicoi formations.

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STRATIGRAPHY AND STRUCTURE OF THE MURPHY MARBLE BELT IN PARTS OF NORTHERN GEORGIA

By
William M. Fairley
Department of Geology
University of Notre Dame
Notre Dame, Indiana 46556

CONTENTS

STRATIGRAPHY AND STRUCTURE OF THE MURPHY MARBLE BELT IN PARTS OF NORTHERN GEORGIA

Previous Work and Purpose of the Present Paper

The term Murphy Marble Belt (or just Murphy Belt) refers to a sequence of metamorphosed sedimentary rocks whose oldest unit is the Nantahala Formation which lies above the Great Smoky Group. The Belt has been mapped in detail locally, but the rock units have been variously subdivided and named, and so it is impossible to make positive correlations from one mapped area to another. Generally the Murphy Belt is considered to occupy a syncline (Keith, 1907; Hurst, 1955) although this has been disputed (Van Horn, 1948). Radically different structural interpretations have been made by some authors, even though they agreed to the presence of a syncline (Bayley, 1928; Fairley, 1965). Graham (1967) briefly summarized arguments for various structural interpretations and offered a new one of his own (that the Murphy Belt occupies a monocline). The purpose of the present paper is to present data on the mineralogy and stratigraphy of the Murphy Belt, especially from the vicinity of Tate and Marble Hill, Georgia. Hopefully this will contribute to our understanding of the origin and structural history of these rocks.

Acknowledgments. I am especially indebted to the heirs of the Estate of Mrs. Jennie Hart Tate for permission to use information from core drilling done on their property; to officials of The Georgia Marble Company, especially Dr. W. Robert Power, for samples and drilling information; and to Mr. George L. Griffeth for information from drilling currently being done on his property.

This paper concerns aspects of a larger study of the stratigraphy and structure of a portion of the Georgia Piedmont extending from Cartersville, Georgia, to North Carolina between the Cartersville Fault and the Dahlonega Belt. Undergraduates have participated in this study and their support has come from National Science Foundation Undergraduate Research Participation programs. These students are: Joseph V. Chernosky, George J. Schneider, Joseph A. Malone, James A. Mulhern, Stephen P. Krchma, and Timothy J. MacCarry. Part of my work was supported by National Science Foundation Grant GP-3133. Mr. John A. Longhi, a student employed by the Department of Geology of the University of Notre Dame, helped assemble data and is

currently determining the composition of garnets in the Murphy Belt.

The Stratigraphic Column and Problems of Nomenclature

Four formations above the Nantahala occur in the area of this study: the Brasstown, Murphy, Marble Hill Hornblende Schist, and Andrews Formations. The Marble Hill Hornblende Schist is of limited extent and will receive only brief attention. The other three formations have been considered important in the stratigraphic column of the Georgia Piedmont for many years. They are not, however, three successive formations simply following each other in time of deposition. Some of the Murphy Marble grades laterally into the Andrews Schist and perhaps also into the Brasstown Formation, as discussed below. Marble bodies may also occur within the upper part of the Brasstown Formation, and strictly speaking, are not part of the Murphy Marble. Also, the Andrews Schist is in places calcareous. Bayley (1928, p. 95) assigned these calcareous rocks to the Murphy Marble, I considered them a facies of the schist (1965, p. 37). In other words, where the schist grades into calc-schists and siliceous marble, I have called the calc-schist and marble a facies of the schist. Where schist grades into pure marble I have called the marble a separate formation (the Murphy Marble). To justify and explain this terminology, I want to quote from the Code of Stratigraphic Nomenclature*. Article 5e states:

*Code of Stratigraphic Nomenclature of the American Commission on Stratigraphic Nomenclature, Am. Assoc. Petroleum Geologists Bull., vol. 45, p. 645-665.

"**Boundaries in facies change.** — Where a unit changes laterally through abrupt gradation into or intertonguing with a markedly different kind of rock, it may be desirable to propose a new unit. An arbitrary boundary may be placed between the two units. Where the area of intergradation or intertonguing is sufficiently extensive, the rocks of mixed lithology may constitute a third independent unit".

The marble is obviously markedly different from the schist and the term Murphy Marble is warranted. The calc-schist and siliceous marble are different from the schist, but whether they merit a separate unit name is a matter of opinion. I prefer not to give them a separate name because if we did, the name could not be Murphy Marble. The reason for this is the concept of homotaxis. (Article 2a of the Code). Unless rock-stratigraphic units have the same order, they cannot be assigned to the same formations. Most of the calc-schists and siliceous marble lie within the Andrews Schist, not between the Brasstown Formation and the schist which is the proper place for the Murphy Marble. Rather than introduce a new formation name, I consider them as a facies of the Andrews Schist.

Facies Changes in the Marble Valley near Tate

Facies changes, some of which can be seen at the north end of the marble valley near Tate, are significant for an understanding of the outcrop pattern and structural setting of the Murphy Belt. Subsequent statements about the rocks of the marble valley near Tate will refer only to its northern end, unless otherwise indicated. A map and sections are shown in figures 1 and 2. To find the location of figure 1 on the Tate quadrangle sheet, note the intersection of Long Swamp Creek with the East Branch. The longitudinal section was constructed by projecting information from drill holes and outcrops either downdip or updip as the case required. The drill holes are located by letters on the maps of figures 1 and 3. Modal analyses (table 1) are identified by the drill hole letter followed by a number indicating the depth at which the samples were taken. Each mode of a sample taken from an outcrop is located by its number on the maps (figures 1 and 3) or by geographic coordinates. Additional notes concerning the modal analyses and the drill holes, including their angle of inclination, appear on page 106.

The valley is bounded on both sides by the Brasstown Formation which consists of metasandstones interbedded with muscovite schists (Fairley, 1965, p. 19). Garnet mica schists and thin metasandstones of the Andrews Formation, and also the Murphy Marble, occur in the valley and along the valley walls between the outcrops of the Brasstown Formation (figure 1). The marble is restricted to the eastern portion of the valley and the schist to the western, but the schist contains calcareous layers. Dolomite apparently constitutes the easternmost portion of the marble. It can be seen in the "Old County Quarry" just southeast of the intersection of Long Swamp Creek and the East Branch, and a little was drilled at the top of holes "A" and "F". No complete section was seen, but we can estimate that a few tens of feet of dolomite occur here. Its presence is critical however for the interpretation of the structure. The dolomite lies at the stratigraphic bottom of the marble according to Reade (1965, p. 69). All the rocks dip to the southeast and if the repetition of the Brasstown Formation on the two sides of the valley is by folding and not faulting, then the eastern outcrops must be overturned. No evidence was found for a fault between the dolomite and the Brasstown Formation, and so the valley occupies an overturned syncline (cross section on fig. 2). An anticline to the east is outlined by the hillock of Brasstown rocks which projects into the Tate valley and disappears beneath the marble due to the fold's southward plunge (Fairley, 1965, plate I). The nose of the anticline is poorly exposed but a sample from one small outcrop shows interbedded carbonate-rich and clastic layers. (Modal analyses 31a to 31d in table 1 show the mineralogy of individual layers while mode 31 gives the totals for the entire thin section.) Interbedding between the Brasstown and Murphy Formations is also evident at Marble Hill (Fairley, 1965, p. 24). The syncline plunges to the south too, as can best be seen by tracing it northward out of the valley to where the Andrews Formation disappears (Fairley, 1965, pl. I). Within the valley folding does not repeat all the rock units; that is, whereas the Brasstown Formation occurs on both limbs of the syncline, the Murphy and Andrews Formations do not. We can interpret their map pattern as due to facies changes. Schists of the Andrews Formation dip eastward on the west side of the valley. Somewhere down dip, before the form of the fold comes to the surface again on the east side of the valley, the schist grades into marble which we see at the surface (cross section on fig. 2). This facies change cannot be observed, and it is of course an interpretation. But facies changes from schist to marble *can* be readily seen in a north-south direction, and indicate the reasonableness of the interpretation. These facies changes are discussed below.

Two small oval areas of siliceous marble surrounded by schists and metasandstones occur along the west side of the valley and occupy topographic lows (asc on fig. 1). Drill hole "C" penetrated a portion of the northern one and the sample for modal analysis 12 was collected in the southern one. A low divide with a small outcrop of garnet mica schist separates these two areas. No folding or faulting is evident which can account for the dis-

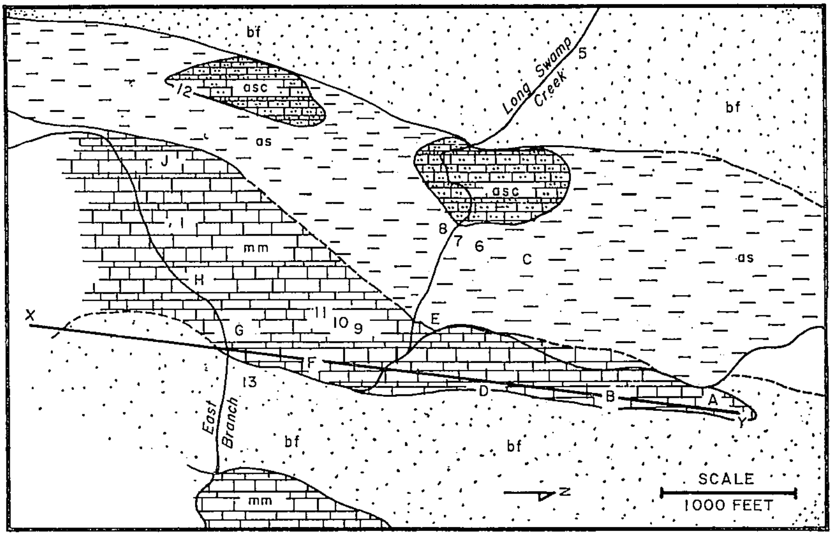

Figure 1—Sketch map of the geology at the north end of the marble valley near Tate. Contacts dashed where inferred. The bedding strikes approximately 20-30 degrees east of north and dips about 30 degrees to the southeast. Capital letters refer to drill hole locations; numbers to outcrop samples. The small letters are explained in the legend of figure 2.

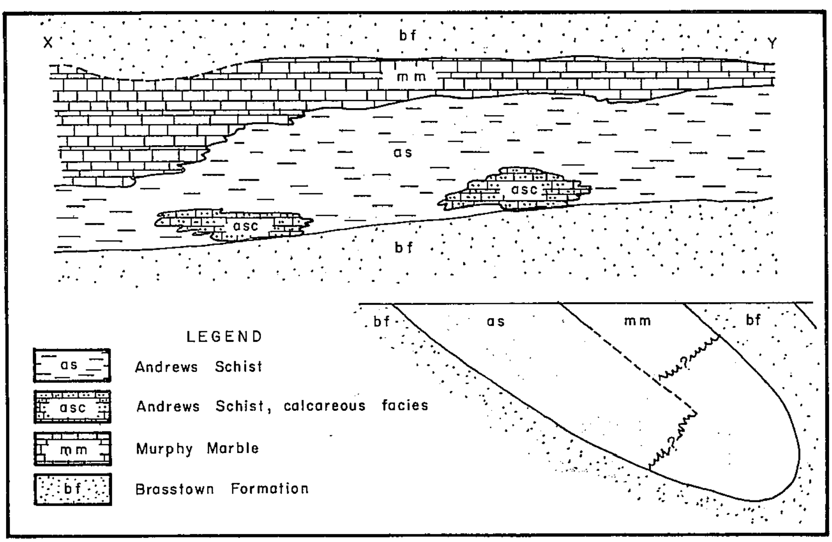

Figure 2—Longitudinal section along line X-Y of figure 1, and a generalized cross section passing near drill hole "F". The question marks in the cross section indicate that the exact place where the marble interfingers with the schist is not known.

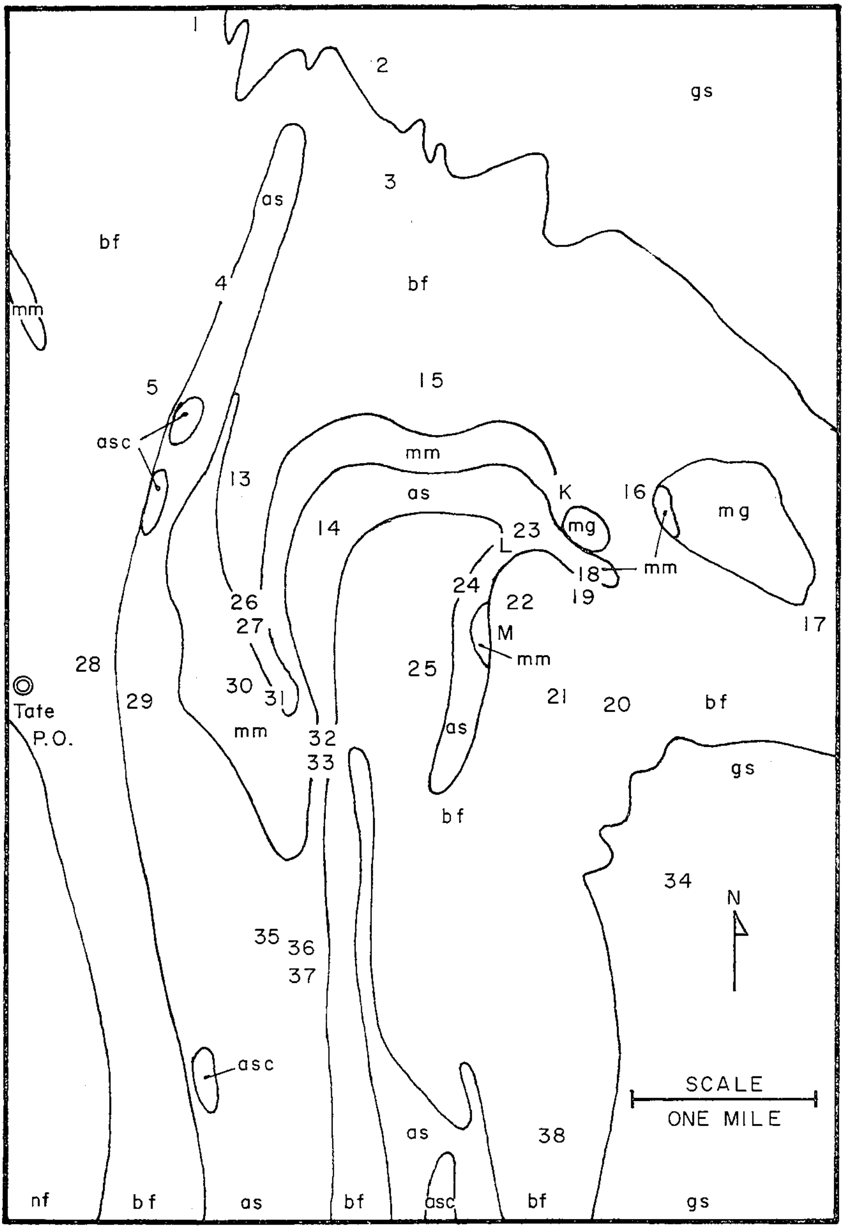

Figure 3—Sketch map showing the locations from which samples for modal analyses were taken. Locations for modes not shown here are given in table 1. gs = Great Smoky Group; nf = Nantahala Formation; bf = Brasstown Formation; mm = Murphy Marble; asc = Andrews Schist, calcarceous facies; as = Andrews Schist.

position of these marbles and the schist. That the marbles grade into schist and then back into marble again along strike seems to be an inescapable conclusion. The marbles themselves are quite quartzose and micaceous. Drilling was done many years ago in the southern area, and I did not see the core until after it had been dumped. The rock is strongly banded with alternating calcite versus quartz-mica layers, neither more than a very few inches thick. Photographs of pieces of the core are shown in Georgia Geological Survey Bulletin 75 (Fairley, 1965, fig. 1 and 2 of pl. 7). Although hole "C" from the northern area showed some relatively pure marble layers a very few feet thick, most of this marble is also quartzose and micaceous. Fluctuations in the original conditions of sedimentation are well-shown in a thin section made from this core (C-189, table 1). Alternating layers some rich in calcite and others in clastics were ruled off on the thin section and counted separately. The first sedimentary layer (C-189-a) is a relatively pure carbonate, the second (C-189-b) is rich in clastics. The third layer (C-189-c) again has much calcite, but not as much as the first. The fourth layer (C-189-d) shows a resurgence of clastic sedimentation. The fifth and sixth layers constitute another cycle (C-189-e and C-189-f). Many such examples of fluctuating conditions of sedimentation can be seen in the drill core. These have profoundly influenced my ideas about the significance of the sporadic distribution of marble bodies throughout the Murphy Belt. Beginning late in Brasstown time, variable amounts of carbonates were deposited in selected localities in the basin of deposition. Whether these were of organic or chemical origin cannot be determined because of the high degree of metamorphism which they have experienced. Thick deposits of calcite accumulated in places and these we now know as the Murphy Marble. Sporadic carbonate deposition continued into Andrews time. Lensing of the carbonate bodies and interfingering with adjacent clastic deposits were common. The faults which bound the marble outcrops on so many maps of the Murphy Belt are generally unwarranted. The discontinuities in the distribution of the marble are mostly due to original conditions of sedimentation and only rarely to faulting.

Other Aspects of the Lithologies in the Marble Valley

Vertical gradation of marble into schist. Several drill holes penetrated the marble-schist contact and show its interbedded nature. Two thin sections were made to show the contact from core of hole "G". Bands of distinctive mineralogy were lined-off and counted separately on the upper thin section (modes G-341-a to G-341-f). The stratigraphic section is overturned here, and the word "upper" refers to how the rocks were encountered in the hole. The top layer is calcite-rich with a little zoisite. In the lower layers lime occurs mostly in zoisite and hornblende, then in plagioclase. A few millimeters below this the next thin section (G-341-g) shows a mineralogy much like that of F-341-a and F-341-b whose lime content is only 1.24 percent as shown by a chemical analysis (number 1 of table 2).

The marble grades upward into the Marble Hill Hornblende Schist in many places to the east of Tate.

Silicate minerals in the marble. Modal analyses of marbles were made to show the nature of the impurities. The non-calcite fractions of some modes were recalculated to 100 percent and the results were plotted on triangular diagrams (fig. 4 and 5). This was done for both the impurities which occur in the Murphy Marble and also for the marbles which occur in the Andrews Schist. Samples from the two formations plot in different areas of the diagrams, although the points are widely scattered. The residues of marbles from the marble valley plot nearer to the Brasstown rocks than to the Andrews rocks. This makes us wonder if there might be some interfingering of the Murphy and Brasstown Formations in the Tate quadrangle which we have not yet recognized. Furcron (1953, p. 36) suggested that the marble in the eastern limb of the Murphy Syncline in southern North Carolina may be interbedded with the Valleytown Formation. The upper part of the Brasstown Formation is calcareous in the Mineral Bluff quadrangle (Hurst, 1955, p. 50, 51) and in the Tate quadrangle (Fairley, 1965, p. 24). The recalculated residue of Hurst's composite mode of calcareous Brasstown rocks would plot near residues from the marble valley (mode no. 56, not plotted in the diagrams). A modal analysis which I made on a metasandstone interbedded with marble in the Campbell quarry of the Mineral Bluff quadrangle shows a typical Brasstown lithology (mode 55). We need more information, but clearly the stratigraphic relations of the marbles in the Murphy Belt are very complex. One of the plotted samples (mode 62) is from the extension of the Hiwassee Formation as mapped by Bayley (1928). No inferences can be drawn from an isolated sample, but I intend to sample calcareous beds which are common in many of the local formations and test the possibility that the silicate residues can be used for stratigraphic correlation. In particular, I want to test the idea that the "Weisner-Wilhite-Hiwassee" coterie is in part equivalent to the Murphy Belt rocks (Fairley, 1966, p. 33).

Chemical composition. Only a few chemical analyses of the Andrews and Brasstown Formations from the Tate area are available (table 2), but they may be of some use in interpreting the origin and history of the rocks. The high alumina content of some of the schists is intermediate between that of the average shale and residual clays reported by Pettijohn (1957, tables 61 and 69). Power (oral communication) suggested the possibility of local unconformities between the marble and overlying Andrews Schist or in the lower part of the schist. The iron deposits located near the base of the schist at many places along the Murphy Belt might have formed as residual accumulations on the erosion surface. This idea warrants further study in view of the high alumina content of some of the schists. A discrepancy occurs in the potash and soda contents as determined by chemical analyses versus calculation from the mode. There is less potash in the analysis than we would expect considering the amount of muscovite in the rock. Perhaps part of the mica is paragonite, not muscovite.

Metagabbro. Hornblende-rich rocks occur sporadically in all the formations of the Murphy Belt and in the underlying Great Smoky Group. Generally it is difficult to determine whether the hornblende has formed from sedimentary or igneous minerals. In two instances the origin seems clear. The hornblende in the Marble Hill Hornblende Schist probably formed from a siliceous, ferruginous dolomite. Pyroxenes, partially or completely altered to hornblende, are quite certainly of igneous origin in the rock which is called metagabbro (Fairley, 1965, p. 30, 42). The ratio of pyroxene to hornblende is highly variable, but most samples consist mostly of hornblende. The metagabbro is characterized by its relatively coarse grain size (hornblende grains up to 1/8 inch long), and by its weak foliation. The hornblende-rich rock shown in mode G-39 strongly resembles the metagabbro. Only 1½ feet of it were drilled, and in only one hole, and we cannot determine whether it cuts the foliation of the marble or not. The calcite and biotite reported in the mode occur generally but not exclusively near the borders of the metagabbro. The mode is a composite count from three thin sections made from the top, middle, and bottom of the sample. The relatively unaltered texture of these and other metagabbros in the Tate and adjacent quadrangles suggests that they originated late in the tectonic history of the region. Whether the gabbros are related to the serpentinized ultramafics, such as occur at Holly Springs, is not known.

East-West Variations in Mineralogy and Texture

The Brasstown and Andrews Formations are very distinctive and easy to tell apart in the Tate valley and to the west. Their texture and mineralogy change to the east, however, and they begin to look quite similar. The interlayering of quartzo-feldspathic beds with schistose beds is not as well-developed in easterly exposures of the Brasstown. In both formations the texture coarsens to the east largely due to the appearance of porphyroblasts of muscovite and "buttons" of kyanite (Furcron and Teague, 1945, p. 40). Also, feldspar becomes more abundant, at least in the Andrews Formation, in rocks to the east. Figures 4, 5, and 6 show plots of these rocks using various end members chosen to bring out both the similarities and the dissimilarities

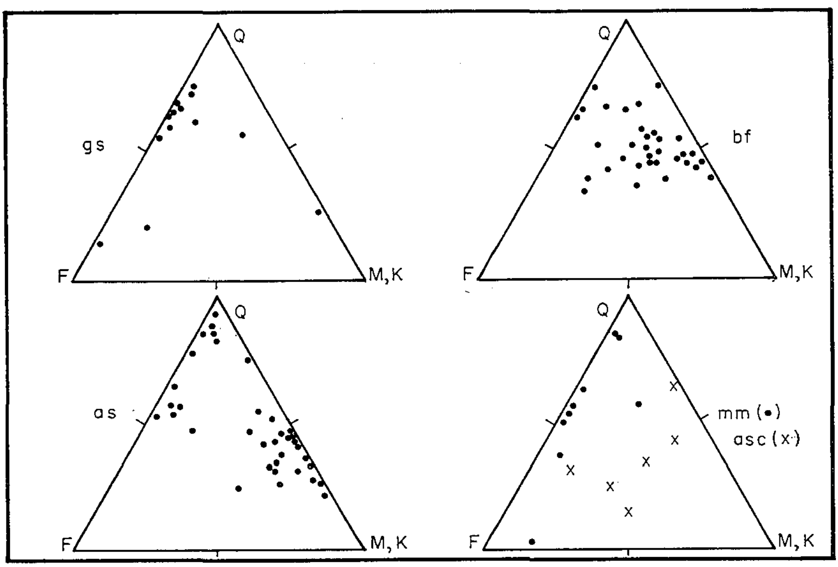

Figure 4—Plot of modal analyses recalculated to three end members. Q = quartz; F = feldspars; M, K = muscovite plus kyanite; gs = Great Smoky Group; bf = Brasstown Formation; as = Andrews Schist; mm = Murphy Marble; asc = Andrews Schist, calcareous facies.

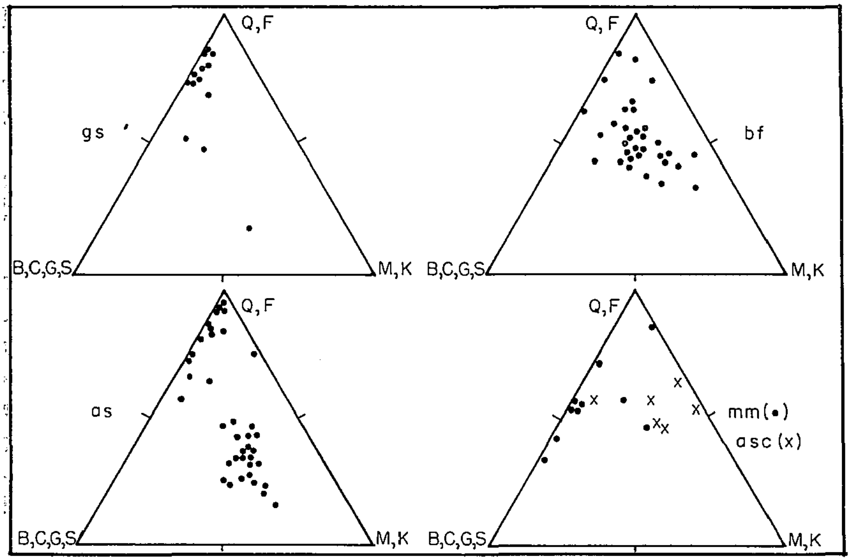

Figure 5—*Plot of modal analyses recalculated to three end members. Q, F = quartz plus feldspars; B, C, G, S = biotite, chlorite, garnet, and staurolite; M, K = muscovite plus kyanite; gs = Great Smoky Group; bf = Brasstown Formation; as = Andrews Schist; mm = Murphy Marble; asc = Andrews Schist, calcareous facies.*

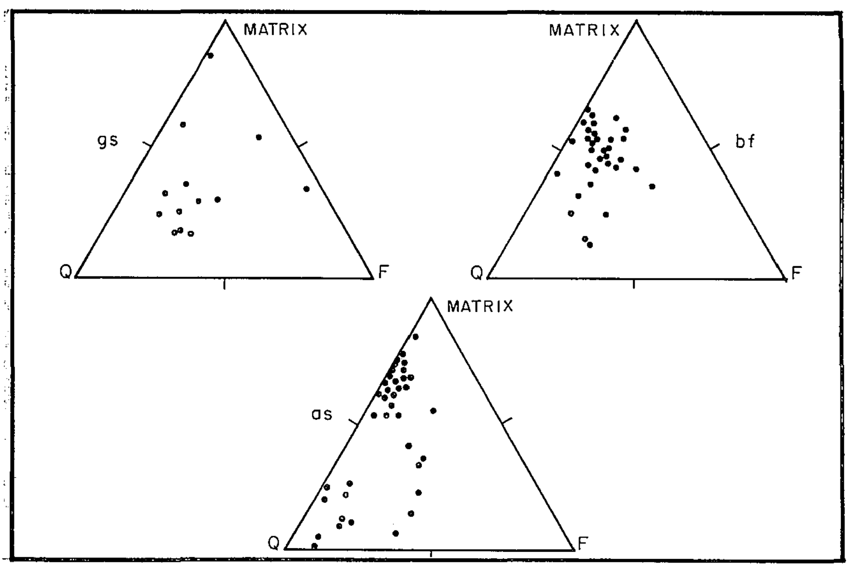

Figure 6—*Plot of modal analyses. Q = quartz; F = feldspars; Matrix = all other constituents; gs = Great Smoky Group; bf = Brasstown Formation; as = Andrews Schist.*

of the two formations. Modes from the Great Smoky Group are added for comparison. The most characteristic feature of the Andrews Formation, the high content of garnets in the schists, is not apparent in these plots, but is obvious from the modes. The garnets have been crushed and smeared through the rocks in places, especially near holes "K" and "L" and to a lesser extent near hole "M". This makes the garnets less obvious in hand specimens, and so it is difficult to assign these rocks to the Andrews or to the Brasstown Formation, especially where the Andrews rocks have abundant feldspar. Even studies with the petrographic microscope do not always unequivocally resolve the problem. Details about the east-west differences in mineralogy of the Andrews and Brasstown Formations are available only from the Tate-Marble Hill area, and even here there are gaps in our information.

Most of the modes done from the Brasstown Formation are from the metasandstones rather than the schists, and modes from western exposures are scanty. The schists in the Brasstown Formation are very much like those of the Andrews Formation except in having relatively few garnets. Also, examination of hand specimens suggests that the Brasstown Formation may be more feldspathic near its base than near its top. It is tempting to say that the easterly increase in feldspar content in the Andrews Formation indicates an easterly source for the original sediments.

The Murphy Marble Belt near Whitestone, Georgia

Power and Reade (1962) did detailed mapping around Whitestone, Georgia. Graham continued this work (1967), subdivided the chlorite-sericite phyllite (unit 7) of Power and Reade, and offered a slightly modified interpretation of the stratigraphy and outcrop pattern. A portion of Graham's map is reproduced in figure 7. He suggested that his outcrop pattern could be interpreted as an overturned anticline or an overturned syncline, but also as a monocline. He slightly preferred the monoclinal interpretation (p. 44). Actually, it is very easy to take one of Graham's cross sections and make an overturned syncline of it by matching-up similar lithologies on opposite sides of the section. This is done in figure 7 where the solid lines show Graham's cross section. Dashed lines have been added to show how plausible a synclinal interpretation really is. Correlating the marble on the east side of the cross section with the epidote-chlorite schist on the western side puts the marble in the overturned limb of the syncline, and we can show that this makes sense. Graham said that the schist was originally a "magnesium mudstone", apparently because of its high magnesia content. The marble is divided into several units, with a dolomite overlying a calcite marble (Power and Reade, 1962, p. 9). However, Reade's work in the Tate-Marble Hill area (1965) indicated that the dolomite is actually at the bottom of the stratigraphic column. Therefore, the dolomite and marble in the mines at Whitestone are overturned just as they should be to fit the interpretation of an overturned syncline.

Lithologic differences within each of the various stratigraphic units as seen on opposite sides of the syncline can be accounted for by minor facies changes. The quartz-muscovite schist and the biotite-quartz schist simply show two aspects of the Brasstown Formation. Next to these Brasstown rocks toward the outer portion of the syncline on both sides of the fold are graphitic

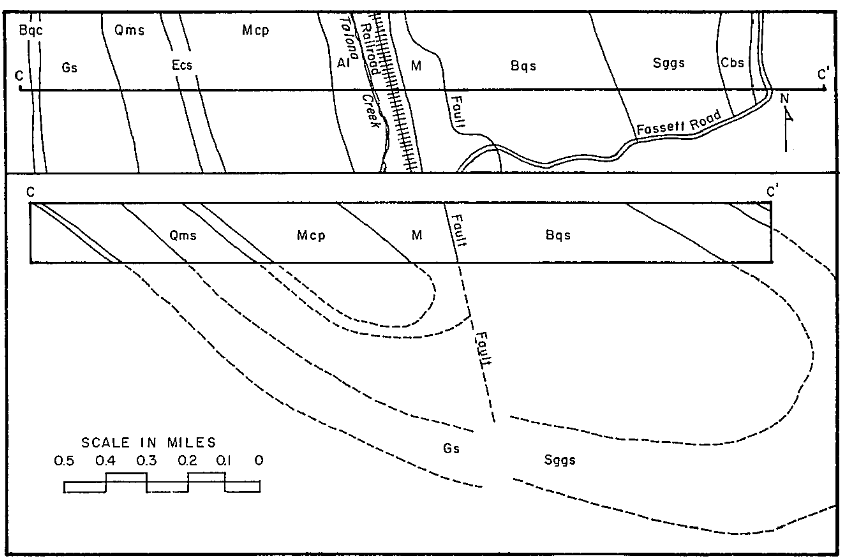

Figure 7—Geologic map (upper diagram) and cross section (lower diagram) near Whitestone, Georgia. Solid lines are from Graham (1967), dashed lines are my own interpretation. Al = Alluvium; Bqc = Blue-quartz conglomerate; Gs = Graphite slate; Qms = Quartz-muscovite schist; Ecs = Epidote-chlorite schist; Mcp = Muscovite-chlorite phyllite; M = Marble; Bqs = Biotite-quartz schist; Sggs = Staurolitz-garnet graphite schist; Cbs = Cross-biotite schist.

formations which are logically correlated with the Nantahala. The conglomerates mapped by Graham offer a complication, but actually confirm the presence of a fold rather than a monocline. Graham shows a conglomerate on both sides of his mapped area, although the eastern conglomerate "grades . . . into a quartzite" (p. 40) before it reaches the southern limit of the map. Both consist of two or more pebble-rich layers interbedded with non-conglomeratic layers in a zone of variable thickness, probably not exceeding about 300 feet. A few cobble-sized fragments are present. Lithologically the conglomerates are very distinct. The pebbles consist of quartz, microcline, perthite, and slivers of blue to black phyllite in a matrix of quartz and feldspar. To correlate such distinct lithologies on two sides of the fold is logical. Clearly, a fold is present at Whitestone, and it is most likely a syncline as indicated for the Murphy Belt to the north by Hurst (1955, p. 72).

A major thrust fault was mapped at Whitestone and was named for that locality by LaForge and Phalen (1913). One purpose of the present paper is to show that the Whitestone thrust is not necessary to explain the local geology. In fact, the evidence strongly suggests that no such thrust exists. The thrust was thought to bring the Nantahala Formation over the Murphy Marble. Faulting is evident near Whitestone as shown on the map of Power and Reade. However, their fault is not a thrust, it does not bring the Nantahala over the Murphy Formation, and both limbs of the syncline are present and intact in at least part of the area. Likewise, the geology of the Tate quadrangle in the Murphy Belt to the south is best explained without recourse to major thrust faulting (Fairley, 1965, p. 9).

Table 1

Modal Analyses of Rocks from the Murphy Marble Belt

Explanatory notes:

1. The Plagioclase is almost all oligoclase. More calcareous varieties may occur in and near marble bodies.
2. Phlogopite is very common in the calcareous rocks, but biotite also occurs in them. Biotite and phlogopite are difficult to distinguish in some fine-grained rocks.
3. Included with sphene may be some rutile and alteration products of ilmenite.
4. Included in "epidote family" are zoisite, clinozoisite, and epidote. Clinozoisite is most common, but zoisite also is found. Epidote generally occurs in the Marble Hill Hornblende Schist.
5. The abbreviations for formation names are as follows: gs = Great Smoky Group; bf = Brasstown Formation; mm = Murphy Marble; asc = Andrews Schist, calcareous facies; as = Andrews Schist.
6. Each modal analysis is identified by a letter or by a number. The letters refer to drill holes and the number following the letter indicates the depth from which core samples were taken. If two samples were taken at the same depth in feet, they are lettered "a" and "b". Modes designated by numbers refer to outcrops from which samples were taken.
7. All the drill holes are located on figures 1 or 3, as are most of the samples from outcrops. Most of the other locations are given by the first letter of the fifteen minute quadrangle sheet on which they occur. This is followed by the latitude and then the longitude which are given only in minutes. A = Acworth; T = Tate; TR = Talking Rock; W = Waleska. Locations indicated by an asterisk are as follows:
   - Mode 55—Campbell quarry, Mineral Bluff quadrangle.
   - Mode 56—From Hurst, 1955, p. 51.
8. If the thin section was subdivided into parts which were counted separately, the last entry indicates the totals for the entire thin section and also the location (except no total is reported for G-341).
9. A few of these modes were published previously in Bulletin 75 of the Georgia Geological Survey.
10. Mode 3 is more feldspathic than most Brasstown rocks perhaps because it is from near the base of the formation. Also, this sample is fine-grained and the minerals were difficult to identify.
11. Mode 15 is from a small outcrop of Andrews rocks which lies above the Brasstown rocks which surround it. If the dip at location 15 is projected downhill, it intersects marble in the valley.
12. Mode 32 shows more plagioclase than most Andrews rocks. Much of this plagioclase is in two small lenses composed almost entirely of quartz and plagioclase. Perhaps the lenses are intrusive, like nearby pegmatites, and the plagioclase may not be indigenous.
13. The quartz to plagioclase ratio in mode C-189 is constant in all the partial counts because it was necessary to use the universal stage to differentiate quartz from feldspar and this was done at once for the entire thin section.
14. The inclination of the drill holes is as follows:
    - A. Vertical
    - B. 75° to the west.
    - C. 45° to the west.
    - D. Vertical.
    - E. 65° to the west.
    - F. 60° to the west.
    - G. Vertical.
    - H. 75° to the west.
    - I. Vertical.
    - J. 45° to the west.
    - K. Vertical.
    - L. Vertical.
    - M. Vertical.

	A-118	B-87	B-299	C-189-a	C-189-B	C-189-c	C-189-d	C-189-e	C-189-f	C-189
Quartz	25.2	8.9	0.1	5.5	10.4	6.8	16.3	14.4	19.7	11.4
Plagioclase	36.0	4.1	9.2	6.7	12.9	8.2	21.0	16.4	24.3	14.1
Muscovite	15.7	0.2		0.7	8.5		2.5	0.7	3.6	2.6
Biotite & Phlogopite	18.7	17.4	20.1	5.5	18.6	13.0	42.0	20.7	36.1	20.7
Chlorite	0.2	2.9	0.5		0.6				0.2	0.2
Garnet	2.7	12.0	2.0			0.7			2.1	0.5
Opaque	1.1	1.9	4.3	2.7	5.2	2.7	11.6	5.7	7.9	5.7
Sphene		1.7	3.9							
Calcite	0.1	42.8	11.4	77.5	40.1	65.2	1.2	40.7	3.6	42.0
Hornblende		3.4	47.7							
Epidote Family		4.5	0.4	1.4	3.7	3.4	5.4	1.4	2.1	2.6
Orthoclase										
Tourmaline									0.4	0.2
Zircon	0.2	0.1	0.1							
Apatite	0.1	0.1	0.3							
Staurolite										
Kyanite										
Unknown										
No. Counted	1,000	1,000	1,000	907	327	146	400	140	468	(2388)
Formation	bf	mm	as							asc
Location	Fig. 1	Fig. 1	Fig. 1							Fig. 1

	E-75	E-118	E-175	E-202	F-51	F-172	F-261	F-341-a	F-341-b	G-39
Quartz	22.1	59.9	30.9	49.7	26.4	8.7	0.4	21.3	20.1	0.1
Plagioclase		31.0		32.0	1.3	3.7	10.4	0.1		4.0
Muscovite	38.9		40.1	4.4	10.5		1.9	50.1	50.7	
Biotite & Phlogopite	10.5	5.3	11.5	10.1	14.4	7.5		9.6	14.0	3.8
Chlorite	6.6		5.5	0.7		0.7		1.8	0.2	1.1
Garnet	17.5	2.9	9.4	1.3		3.3		14.8	12.8	
Opaque	2.4	0.7	2.3	0.7	4.1	1.6	5.8	1.6	0.8	1.6
Sphene					1.3	0.2		0.4	1.0	1.5
Calcite				0.7	34.8	66.0	81.3			6.8
Hornblende						4.9				80.8
Epidote Family					7.1	3.3				0.3
Orthoclase										
Tourmaline	0.1		0.1						0.1	
Zircon		0.1		0.1			0.2		0.1	
Apatite	0.1	0.1	0.2	0.3	0.1	0.1		0.3	0.1	
Staurolite	1.8								0.1	
Kyanite										
Unknown										
No. Counted	1,000	1,000	1,000	1,000	1,000	1,500	1,000	1,500	2,000	1,500
Formation	as	as	as	as	mm	mm	mm	as	as	mm
Location	Fig. 1	Fig. 1	Fig. 1	Fig. 1	Fig. 1	Fig. 1	Fig. 1	Fig. 1	Fig. 1	Fig. 1

	G-127	G-341-a	G-341-b	G-341-c	G-341-d	G-341-e	G-341-f	G-341-g	H-252	H-269
Quartz	14.6	9.6	27.6	30.2	19.8	8.3	14.8	27.5	26.4	24.0
Plagioclase					43.2	56.4	20.4			
Muscovite	9.0					4.0	25.5	40.3	0.8	46.6
Biotite & Phlogopite	6.2	3.6			19.7	15.7	14.1	13.2	14.6	9.5
Chlorite			0.6		1.3	2.1	3.1	2.6	0.9	3.0
Garnet				1.6	12.6	11.4	21.1	13.9		14.8
Opaque	3.6		0.8	1.3	1.9	2.1	0.9	1.5	3.8	0.4
Sphene	3.0		6.0	2.0				0.1	4.3	0.7
Calcite	63.6	69.4	0.8	2.0	0.2			0.3	30.4	
Hornblende		3.6	48.0	15.6					4.4	
Epidote Family		13.4	16.2	47.0					14.4	
Orthoclase										
Tourmaline										0.4
Zircon		0.2			0.2			0.4		
Apatite		0.2		0.3	0.7			0.2		0.3
Staurolite										0.3
Kyanite										
Unknown					0.4					
No. Counted	500	500	363	307	429	480	431	1,000	1,000	1,000
Formation	mm	mm						as	mm	as
Location	Fig. 1	Fig. 1	Fig. 1	Fig. 1	Fig. 1	Fig. 1	Fig. 1	Fig. 1	Fig. 1	Fig. 1

	I-164	J-99	K-24	K-37	L-65	L-115	L-165	L-165-a	L-215	L-265
Quartz	76.4	77.4	34.3	32.0	33.5	25.3	36.6	37.6	21.4	26.0
Plagioclase	11.3	11.8	21.2	20.7	7.4	9.9	20.1	27.4	5.5	7.3
Muscovite	0.4	1.5	19.1	10.1	19.9	26.6	5.7	5.2	36.0	27.0
Biotite & Phlogopite	8.7	3.0	20.4	33.9	7.9	14.1	23.0	16.0	19.8	10.3
Chlorite	0.3	2.5			4.9	0.3				
Garnet	1.8	2.2	2.4	0.7	3.6	8.7	11.9	12.6	5.0	16.2
Opaque	1.0	0.6	2.2	2.4	3.3	2.4	2.3	1.2	2.6	1.2
Sphene										
Calcite		0.5								
Hornblende										
Epidote Family		0.4								
Orthoclase										
Tourmaline				0.1						
Zircon			0.3	0.1		0.2	0.2			
Apatite	0.1	0.1	0.1							
Staurolite					0.9	1.8			3.3	0.5
Kyanite					18.5	10.3			6.2	10.8
Unknown					0.1	0.4	0.2		0.2	0.7
No. Counted	1,000	1,000	1,000	1,000	1,000	1,000	1,000	500	1,000	1,000
Formation	as	as	bf	bf	as	as	as	as	as	as
Location	Fig. 1	Fig. 1	Fig. 3	Fig. 3	Fig. 3	Fig. 3	Fig. 3	Fig. 3	Fig. 3	Fig. 3

	L-315	L-415	L-465	M-10	M-60	M-110	M-110-a	M-160	M-210	M-260
Quartz	41.6	20.6	38.4	39.6	39.2	78.0	58.5	45.3	36.2	37.1
Plagioclase	3.5	10.0	6.7	9.6	4.1	1.6	26.2	15.3	14.7	14.3
Muscovite	23.3	29.1	20.8	24.2	33.3		2.1	0.4	18.8	23.4
Biotite & Phlogopite	10.0	9.3	8.6	15.2	14.2		12.4	33.2	23.7	15.8
Chlorite	0.1	5.6	1.2	0.1						
Garnet	6.0	13.6	16.8	2.4	2.7	0.3	0.3	5.1	3.1	3.8
Opaque	2.2	2.6	1.8	3.0	2.6	0.6	0.5	0.5	1.1	3.2
Sphene										
Calcite						0.6				
Hornblende						14.9				
Epidote Family						4.0				
Orthoclase										
Tourmaline		1.4								
Zircon			0.1	0.1					0.2	
Apatite					0.8			0.2	0.2	0.1
Staurolite	0.2	1.0			0.1					
Kyanite	13.0	6.5	5.3	5.8	3.0				2.0	2.3
Unknown	0.1	0.3	0.3							
No. Counted	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Formation	as	as	as	bf	bf	bf	bf	bf	bf	bf
Location	Fig. 3	Fig. 3	Fig. 3	Fig. 3	Fig. 3	Fig. 3	Fig. 3	Fig. 3	Fig. 3	Fig. 3

	M-745	M-760	1	2	3	4	5	6	7	8	9	10
Quartz	22.4	20.2	41.7	52.3	27.8	43.9	46.6	69.8	73.0	70.4	10.5	1.5
Plagioclase	8.9	21.9	11.5	31.0	29.5	1.7	27.6	6.7	0.6	15.5	3.5	0.1
Muscovite	31.2	25.0	20.2		12.9	43.0	0.8	7.6	21.1	0.7		1.8
Biotite & Phlogopite	13.6	11.9	25.7	16.4	24.6	6.0	21.4	8.3	0.4	8.7	5.3	
Chlorite						0.7		0.3		0.8	0.6	
Garnet	4.9	11.2			0.8	0.1	1.2	0.3		0.8		
Opaque	2.7	1.9	0.7	0.3	3.7	4.0	2.4	1.0	2.2	1.0	2.9	0.1
Sphene						0.2			2.4		0.2	0.3
Calcite								6.0			58.8	96.1
Hornblende											16.2	
Epidote Family											2.0	
Orthoclase					0.4					2.0		
Tourmaline			0.1		0.3					0.1		
Zircon		0.1	0.1						0.2			
Apatite	0.1	0.1										0.1
Staurolite	2.1	0.9										
Kyanite	14.1	6.8										
Unknown						0.4			0.1			
No. Counted	1,000	1,000	686	1,000	830	1,029	500	1,500	1,000	1,000	905	1,000
Formation	as	as	bf	gs	bf	bf	bf	asc	as	as	mm	mm
Location	Fig. 3	Fig. 3	Fig. 3	Fig. 3	Fig. 3	Fig. 3	Fig. 1 & 3	Fig. 1	Fig. 1	Fig. 1	Fig. 1	Fig. 1

	11	12-a	12-b	12-c	12	13	14	15	16
Quartz Plagioclase	9.8 4.5	45.9	20.7	45.4	31.4	36.1 3.8	31.6 1.6	36.1 3.7	33.7 14.7
Muscovite	0.2	0.6	2.2	1.5	1.7	43.0	36.8	38.7	29.1
Biotite & Phlogopite	8.2	40.3	8.1	45.4	22.8	10.8	4.8	12.5	14.7
Chlorite	2.3								
Garnet	3.9					2.0	21.1	7.3	5.5
Opaque	1.5	3.7	2.2	5.1	3.1	2.9	0.6	1.2	1.7
Sphene	0.4	7.4	2.1	2.6	3.6		0.7	0.3	
Calcite	66.9	1.2	64.2	0.0	36.8				
Hornblende									
Epidote Family	2.2	0.0	0.1	0.0	0.1				
Orthoclase									
Tourmaline								0.2	0.2
Zircon									
Apatite	0.1								
Staurolite							2.4		
Kyanite									
Unknown		0.9	0.4	0.0	0.5	1.4	0.4		0.4
No. Counted	1,000	325	679	194		2,100	1,206	2,002	1,103
Formation	mm				asc	bf	as	as	bf
Location	Fig. 1				Fig. 1	Fig. 1&3	Fig. 3	Fig. 3	Fig. 3

	17	18	19	20	21	22	23	24	25
Quartz	25.5	39.6	30.0	23.6	38.3	37.8	37.2	30.1	33.7
Plagioclase	12.6	7.3	13.9	17.5	6.9	8.3	10.5	7.6	
Muscovite	27.4	16.9	17.9	9.9	31.8	22.0	19.9	31.9	49.3
Biotite & Phlogopite	23.9	23.2	24.6	39.5	9.2	25.2	11.3	12.3	7.2
Chlorite							1.0		0.2
Garnet	1.3	1.9	2.7	3.0	3.1	2.1	8.9	8.7	3.6
Opaque	2.1	1.0	1.5	0.6	6.9	3.2	1.5	2.1	0.6
Sphene									
Calcite									
Hornblende									
Epidote Family									
Orthoclase			2.0	2.1					
Tourmaline		0.2		0.6				1.0	
Zircon					0.1				
Apatite					0.4		0.5		
Staurolite	0.1				0.1			0.5	0.4
Kyanite	7.0	9.9	7.4	3.2	3.2	1.4	9.2	5.6	1.2
Unknown	0.1							0.2	3.8
No. Counted	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,075
Formation	bf	bf	bf	bf	bf	bf	as	as	bf
Location	Fig. 3	Fig. 3	Fig. 3	Fig. 3	Fig. 3	Fig. 3	Fig. 3	Fig. 3	Fig. 3

	26	27	28	29	30	31-a	31-b	31-c	31-d
Quartz	39.6	50.6	59.8	37.2	4.5	32.0	30.8	40.5	33.8
Plagioclase	13.1	14.5	21.2		25.4				
Muscovite	24.6	15.0	8.9	39.6		2.3	1.4	1.1	0.0
Biotite & Phlogopite	17.3	18.0	7.8	9.1	1.4	63.4	33.2	55.2	15.6
Chlorite	0.8		0.9						
Garnet	3.8	0.7		11.1					
Opaque	0.5	1.0	1.3	1.2		0.5	0.5	0.4	1.3
Sphene	0.2	0.1		0.6	7.5	1.8	0.5	2.8	2.6
Calcite					8.3		33.6		46.7
Hornblende					43.9				
Epidote Family					9.0				
Orthoclase									
Tourmaline	0.1	0.1							
Zircon			0.1						
Apatite									
Staurolite				1.2					
Kyanite									
Unknown				.01					
No. Counted	1,000	1,000	1,000	1,050	1,041	219	214	458	77
Formation	bf	bf	bf	as	mm				
Location	Fig. 3	Fig. 3	Fig. 3	Fig. 3	Fig. 3				

	31	32	33	34	35	36	37	38	39
Quartz	36.0	36.0	25.6	52.4	83.0	41.0	86.8	36.5	58.5
Plagioclase		27.0		25.3	7.7	34.5	7.8	4.2	0.9
Muscovite	1.3	14.0	35.8	1.3	5.4		3.4	36.6	19.3
Biotite & Phlogopite	49.0	17.6	5.1	16.0	3.8	23.9	1.9	13.4	19.1
Chlorite		0.6							
Garnet		3.2	14.0	3.9				3.3	
Opaque	0.5	1.6	0.4	0.8		0.2	0.1	4.9	0.5
Sphene	2.1		0.4					0.2	
Calcite	11.1								0.6
Hornblende									
Epidote Family									0.1
Orthoclase									
Tourmaline								0.1	0.3
Zircon					0.1			0.1	0.3
Apatite								0.7	
Staurolite			18.5						
Kyanite			0.2						
Unknown				0.3		0.4			0.4
No. Counted	(968)	500	1,000	1,079	2,000	1,000	1,057	1,500	1,033
Formation	bf	as	as	gs	as	as	as	bf	bf
Location	Fig. 3	Fig. 3	Fig. 3	Fig. 3	Fig. 3	Fig. 3	Fig. 3	Fig. 3	T-27.6 — 24.0

	40	41	42	43	44	45	46	47	48	49
Quartz	56.1	41.8	22.5	34.3	59.4	7.0	13.2	33.6	16.7	10.8
Plagioclase	27.3	28.8	19.1	1.9	19.2	12.5	23.1	14.6	0.4	38.4
Muscovite		3.4	21.6	27.6	5.6	9.5	6.3	25.1	45.7	11.6
Biotite & Phlogopite	15.9	25.5	29.4	18.5	15.6	5.0	21.3	16.8	20.8	34.6
Chlorite						0.6	0.2			
Garnet	0.2	0.2	3.6	3.9				7.0	10.3	3.2
Opaque	0.3	0.3	1.5	0.6	0.2	0.7	0.5	1.3	0.8	0.4
Sphene	0.1							0.7	0.6	
Calcite						64.4	35.0			
Hornblende										
Epidote Family						0.3	0.4			
Orthoclase										
Tourmaline			0.3					0.4	0.1	0.2
Zircon									0.1	0.4
Apatite	0.1							0.5		0.4
Staurolite										
Kyanite			2.0	13.2					4.5	
Unknown										
No. Counted	1,500	2,000	1,000	1,000	1,500	1,000	887	2,475	2,043	1,500
Formation	gs	gs	bf	bf	gs	asc	asc	bf	gs	gs
Location	T-27.3	T-27.0	T-25.2	T-25.0	T-24.7	T-21.7	T-21.6	T-21.1	T-19.8	T-19.9
	-17.3	-17.1	-18.1	-18.1	-24.1	-21.4	-21.1	-21.1	-18.8	-20.8

	50	51	52	53	54	55	56	57	58
Quartz	14.8	59.7	15.0	7.5	36.3	41.2	25.9	77.0	64.9
Plagioclase	7.1	11.6		60.9	3.6	13.1	12.0	1.9	8.1
Muscovite	17.4	19.4	8.7	3.0	27.7	23.6	3.4		0.8
Biotite & Phlogopite	8.0	8.3	0.4	24.3	24.2	17.4	27.7	12.1	18.7
Chlorite	2.7		0.1		0.1	1.2	2.1	0.7	0.5
Garnet					7.0	0.2	3.9	6.7	5.5
Opaque	0.8	0.6		4.3	0.8	2.1	1.4	0.8	1.2
Sphene		0.4	0.2						
Calcite	44.6		75.5			0.7	23.6		
Hornblende									
Epidote Family	4.5		0.1						
Orthoclase									
Tourmaline					0.2				
Zircon						0.2		0.1	0.3
Apatite								0.4	
Staurolite									
Kyanite									
Unknown					0.1	0.3		0.3	
No. Counted	827	2,388	1,012	2,000	1,000	1,000		1,000	1,000
Formation	asc	bf	asc	gs	bf	bf	bf	as	as
Location	T-20.5	T-20.1	T-19.4	T-19.1	T-15.1	*	*	A-14.3	A-14.3
	-23.6	-24.8	-25.1	-20.7	-27.2			-33.8	-33.9

	59	60	61	62	63	64	65	66	67
Quartz	28.9	14.7	8.7	23.6	46.0	37.2	54.5	52.6	34.6
Plagioclase	6.2	1.2	1.3	5.9	20.3	33.0	28.8	17.7	8.9
Muscovite	39.5	56.3	19.9	26.1	10.8	2.1	0.9	5.2	22.5
Biotite & Phlogopite	11.2	15.3	8.0		21.4	26.4	15.8	18.6	29.9
Chlorite	4.2	3.5	3.6	0.5				0.4	
Garnet	7.0	5.4				0.2		4.2	
Opaque	2.7	3.3	0.4	5.1	0.9	0.9		0.7	2.0
Sphene			0.4		0.4				0.3
Calcite		.01	38.6	38.8					
Hornblende									
Epidote Family			19.1						
Orthoclase									1.5
Tourmaline	0.1							0.4	
Zircon	0.1				0.2	0.1			
Apatite									0.1
Staurolite									
Kyanite									
Unknown	0.1	0.2				0.1		0.2	0.2
No. Counted	1,000	1,000	1,042	1,023	1,000	1,000	2,000	1,064	2,000
Formation	as	as	asc		gs	gs	gs	gs	gs
Location	A-14.4 -34.5	A-12.8 -33.8	T-15.8 -28.3	W-20.7 -38.2	TR-31.7 -34.3	TR-31.3 -33.9	T-25.0 -15.9	T-23.3 -26.8	T-23.2 -28.3

Table 2

Chemical Analyses of Rocks from the Murphy Marble Belt

	1	2	3	4	5	6
SiO_2	56.24	54.8	72.10	80.18	58.34	43.52
TiO_2	1.45	0.1				3.07
Al_2O_3	21.84	22.5	14.02	10.54	23.33	13.82
Fe_2O_3	2.57	1.7		4.66	8.13	3.24
FeO	6.73	8.4				8.07
MnO	0.086	0.1				0.078
MgO	2.90	2.5			1.96	11.87
CaO	1.24	0.2	6.50	1.38	5.60	11.63
Na_2O	1.19	0.7			2.20	2.23
K_2O	3.03	5.9	3.20	2.64	0.80	0.15
H_2O	1.98	2.9				1.28
P_2O_5	0.285	0.1				0.629

1. Andrews Schist from drill hole "F" at a depth of 341 feet. Analysed at the Colorado Assaying Co.
2. Analysis calculated from the mode, same location as number 1.
3. Metasandstone in the Andrews Schist from location 6. L. H. Turner analyst, Georgia Geol. Survey.
4. Metasandstone from the Brasstown Formation at location 28. L. H. Turner, analyst, Georgia Geol. Survey.
5. Andrews Schist from location 32. L. H. Turner, analyst, Georgia Geol. Survey.
6. Metagabbro from drill hole "G" at a depth of 39 feet. Analysed at the Colorado Assaying Co.

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ISOTOPIC DATING AND METAMORPHIC ISOGRADS OF THE CRYSTALLINE ROCKS OF GEORGIA

By

James W. Smith

Georgia Department of Mines, Mining and Geology

Atlanta, Georgia 30334

J. M. Wampler

Georgia Institute of Technology

Atlanta, Georgia 30332

and

Martha A. Green

Georgia Department of Mines, Mining and Geology

Atlanta, Georgia 30334

CONTENTS

Abstract

Dates on micas are, in general, about 350 million years on the northwest side of the Georgia crystallines and 250 million years on the southeast. The metamorphic isograds of the crystallines form a simple pattern, indicating one period of metamorphism spanning both Acadian and Alleghanian orogenies, with cooling beginning on the northwest and progressing southeastward. The two westernmost mica dates are older than 350 million years and may be from Precambrian rocks with micas reset below recrystallization temperature, or the dates are the time or times of intrusion or metamorphism near the Ordovician-Silurian boundary and in the Devonian. Five new K-Ar dates are given in this article.

Zircon dates from a granite and granite gneiss are about 450 million years. This is highly suggestive of Taconic granitic intrusion and/or granitization but may reflect some other thermal event.

Future projects of the Georgia Geological Survey in cooperation with the Georgia Institute of Technology will likely include dating rocks of the Grenville orogenic cycle, younger intrusions and periods of metamorphism, and times of fault movement. Also, some of the stratigraphy of the Piedmont may be established by dating zircons from the metamorphosed extrusive rocks. A few core samples from the basement beneath the Coastal Plain will be dated by the whole-rock Rb-Sr method.

Acknowledgments

Benjamin A. Morgan, III of the U. S. Geological Survey allowed James W. Smith a preview of his map (in preparation) of metamorphic isograds in the eastern United States. The present study was begun prior to Dr. Morgan's.

W. Robert Power, Professor of geology at Georgia State College, read the final manuscript and collected a hornblende sample for isotopic dating.

Willard H. Grant, Professor of geology at Emory University, made several critical corrections on the location of metamorphic isograds based upon his field experience.

A. S. Furcron, Director of the Georgia Geological Survey, supplied his field maps covering many of the crystalline counties, and from memory, he was able to add several bits of vital data.

The sericite isograd of Plate 1 (in pocket) is the first appearance going eastward of well crystallized sericite from illite as

shown by the work of Charles E. Weaver, Director of the Geophysical Sciences Group, Georgia Institute of Technology. and James W. Smith. Their paper (in preparation) is tentatively titled "Metamorphism and weathering of some argillaceous rocks in Northwest Georgia."

The equipment used for argon analyses at the Georgia Institute of Technology was obtained under a program initiated by Dr. Weaver through grants from the Gulf Research and Development Corporation and from NASA.

Potassium analyses at the Georgia Institute of Technology were carried out under the guidance of Kevin Beck.

Mineral separations were by J. Roger Landrum and Walter C. Turner of the Georgia Geological Survey using heavy-liquid, magnetic, and hand-picking techniques. The manuscript was typed and edited grammatically by Judy A. Norris.

Introduction

The Geophysical Sciences Group of the Georgia Institute of Technology has recently acquired the personnel and equipment to determine K-Ar dates of rocks and minerals. The Georgia Geological Survey, with field equipment and experienced hardrock geologists, has joined the Georgia Institute of Technology in a program of isotopic dating of the crystallines of Georgia. In addition to the K-Ar program, which is just getting underway, equipment is being obtained for Rb-Sr and U-Pb analyses. This paper reviews the earlier age determinations, adds a few dates, and suggests the pattern of future isotopic dating studies.

Compilation of Dates

Isotopic dates on thirty-one mineral samples from Georgia have been reported by previous workers, and five new samples are included in this report for a total of thirty-six Georgia samples from twenty-seven localities (Pl. 1, in pocket). Included in these are one sample of hornblende, three zircon samples, and the remainder are biotite and muscovite. A K-Ar date is given for the hornblende, U-Pb (and Th-Pb) dates are given for the zircons, and twelve Rb-Sr dates and twenty-one K-Ar dates are given for the micas. References to dates by previous workers are in a special reference section near the end of this article, and detailed descriptions of the sample localities follow Table 1.

TABLE 1

NEW GEORGIA DATES

Plate 1 Locality No.	Date[1] in millions of years	Method	Mineral
2. Fort Mountain	375±20	K-Ar	Biotite
3. Tate	355±20	K-Ar	Hornblende
4. Allatoona	430±25	K-Ar	Biotite
14. Forest Park	320±15	K-Ar	Biotite
27. Thomaston	300±15	K-Ar	Biotite

[1] $\lambda_e = 0.585 \times 10^{-10}$ yr^{-1}, $\lambda_\beta = 4.72 \times 10^{-10}$ yr^{-1}, $K^{40}/K = 0.000119$ (atomic). A description of analytical methods and complete analytical data will be published later.

Sample Localities for Isotopic Dates Shown on Plate 1 (in pocket).

1. Fannin County, 1½ miles S. E. of McCaysville, on Ga. Hwy. 245.
Biotite and muscovite from a fine-grained metamorphic rock in the highly altered shear zone of the Talladega "Series" (Long and others, 1959, p. 600).

2. Murray County, 5¼ miles S. E. of Chatsworth, on U. S. Hwy. 76.
Biotite from the Fort Mountain Gneiss.

3. Pickens County, Harrington Property, 1.2 miles (airline) S. of Marblehill, 0.5 miles (airline) N. of Arborhill Church.
Hornblende from the Marblehill Hornblende Schist (Collected by Dr. W. R. Power.)

4. Bartow County, N. of Cooper Branch Landing, about ½ mile N. of the Allatoona Dam, at the picnic area.
Biotite from Corbin Granite.

5. Gwinnett County, Buford dam site, near Buford.
Biotite from a quartz-feldspar gneiss. "Biotite is brown to deep olive green, fine-grained and associated with equally coarse muscovite. Both minerals have a strong preferred orientation as do elongate areas of strained quartz. Quartz is the dominant mineral, plagioclase the sole feldspar. Garnet, apatite, epidote and iron ore occur as discrete grains scattered through rock." (Long and others, 1959, p. 602).

6. Elbert or Oglethorpe County.
Zircon from Elberton Granite saprolite (Grunenfelder and Silver, 1958, p. 1574).

7. Elbert County, Comolli Quarry, N. W. of Elberton.
Zircon from Elberton Granite (Grunenfelder and Silver, 1958, p. 1574).

8. Elbert or Oglethorpe County, "Collected by Pinson at the stone cutting mill, 1¼ miles west of Elberton, Ga. on the Atlanta-Elberton highway. Sample was not collected in place, but is typical of this well-known monumental stone." (Pinson and others, 1958, p. 58).
Biotite and muscovite from Elberton Granite (Pinson and others, 1958, p. 58).
[The potassium-argon biotite age, 235 million years, is Tilton's (1965, p. 217) calculation and is the one used in the present article. Pinson, using a less acceptable decay constant, calculated the age as 256 million years.]

9. Elbert County, Elberton City Quarry.
Biotite from Elberton Granite. "Microcline is the dominant feldspar with sodic plagioclase present in subordinant amounts; both feldspars are nearly free of sericite. Quartz extinction varies from uniform to undulatory. Biotite is fine-grained, marginally replaced by muscovite, the latter also occurring as separate flakes. Allanite rimmed by epidote is common in the rock and

often occurs replacing the biotite. Iron ore, zircon and apatite are also present." (Long and others, 1959, p. 601).

10. Clarke County, Athens Area.

The biotite dated was a very clean, medium-grained mica taken from a migmatitic gneiss. Chlorite was almost totally absent from the rock (Kulp and Eckelmann, 1961 p. 414).

11. Fulton or DeKalb County, Atlanta Area.

Biotite from a granitic gneiss (Kulp and Eckelmann, 1961, p. 409).

12. Fulton County, Chain Gang Quarry, Ben Hill, ¼ mile S. of Fairburn Road adjacent to the Atlantic Coast Line Railroad.

Biotite from Ben Hill Granite (Pinson and others, 1958, p. 58).

13. Fulton County, ⅓ S. of the junction of Butner Road and Tell Road, 3¼ miles S. of Ben Hill.

Biotite from a quartz-feldspar gneiss (Pinson and others, 1958, p. 58).

14. Clayton County, Dixie Lime and Stone Quarry, 0.9 miles (airline) S. 45° W. of Forest Park city limits, on the east bank of the Flint River, 0.8 miles (airline) N. of the Flint River-Mud Creek confluence.

Biotite from a gneiss.

15. Gwinnett County, Quarry 4 miles E. of Snellville, on U. S. Hwy. 78.

Biotite from Lithonia Gneiss. "Biotite is fine-grained, deep olive green in color, often partly or completely rimmed by muscovite. Muscovite is very pale green in color, occurs both in association with and distinct from biotite flakes and often has an irregular surface appearance. Sphene grains occur both in clusters and marginal to iron ore. Epidote and clinozoisite appear to be altered products of biotite. Grains of allanite are rimmed by epidote and both are associated with biotite. Microcline and plagioclase are almost devoid of sericite. Quartz usually shows uniform extinction." (Long and others, 1959, p. 601).

16. DeKalb or Gwinnett County.

Biotite from Stone Mountain Granite (Pinson and others, 1958, p. 58).

17. DeKalb County, Stone Mountain.

Muscovite from Stone Mountain Granite. "Fine-grained muscovite is common throughout the rock with only minor amounts of brown biotite present, the latter always occurring in association with muscovite. Occasional flakes of muscovite are bent, while some biotite is extensively altered to chlorite. Microcline and plagioclase are medium-grained and nearly void of sericite; quartz has nearly uniform extinction. Epidote and clinozoisite are present in association with the muscovite." (Long and others, 1959, p. 601).

18. DeKalb County, Rock Chapel Quarry.

Zircon from Lithonia Gneiss (Grunenfelder and Silver, 1958, p. 1574).

19. DeKalb County, Rock Chapel Quarry. (Pinson and others, 1958, p. 58).

If this biotite sample is from Rock Chapel Quarry, as stated by Pinson, the rock type is Lithonia Gneiss (Herrmann, 1954). On page 59 of Pinson's article he lists this sample as coming from Stone Mountain Granite composite. Since Pinson gives two different rock types for one sample, there is some question as to the location and rock type for this sample.

20. DeKalb County, Mount Arabia Quarry.

Biotite and muscovite from Lithonia Gneiss (Pinson and others, 1958, p. 58).

21. DeKalb County, Quarry at Flat Shoals of South River, Ga. Hwy. 155.

Biotite and muscovite from Panola Granite (Pinson and others, 1958, p. 58).

22. Greene County, Greensboro Area.

Biotite from Palmetto-type Granite (Kulp and Eckelmann, 1961, p. 409).

23. Fayette County, Tyrone area.

Biotite from a porphyritic granite (Kulp and Eckelmann, 1961, p. 409).

24. Hancock County, Sparta Area.

Biotite from an intrusive granite. "Relic textural features and extensive zoning of feldspar crystals are seen and indicate an igneous origin, while irregular interlocking grain boundaries, alteration of feldspars, and shredding and chloritization of biotite suggest later deformation, alteration, and limited recrystallization." (Kulp and Eckelmann, 1961, p. 414).

25. Bibb County, Lorane Area, N.W. of Macon.

The biotite dated was a very clean, medium-grained mica taken from a migmatitic gneiss. Chlorite was almost totally absent from this rock (Kulp and Eckelmann, 1961, p. 409).

26. Upson County, Mauldin Mine, on Whittle Road, 3.7 miles S. 24° E. of Thomaston, about one mile off the Thomaston-Butler Hwy.

The biotite and muscovite dated had clay stains but no inclusions and came from a pegmatite. The biotite was in two- by three-inch sheets. The muscovite was brownish and in one- by two-inch books (Deuser and Herzog, 1962, p. 1998; and Heinrich, E. W., and others, 1953, p. 335).

27. Upson County, Mitchell Creek Mica Mine, 7¼ miles (airline) S. 65° E. of Thomaston, 1 mile N. E. of Wymanville, on small branch of Tobler Creek.

Biotite from a large, fresh single crystal of mica.

Geologic Interpretation

U(Th)-Pb Dates

All uranium (thorium)-lead dates are on zircon samples from three localities. Two of these were from an igneous formation, and the third was from a gneiss having some possible sedimentary features. Essentially concordant U-Pb determinations for each of the three localities suggests plutonic activity and cooling over a broad segment of the Georgia Piedmont during the Taconic orogeny, for the dates average about 450 million years. (Range is from 415 million years to 490 million years.) (Th-Pb dates are ignored, as they are generally unreliable.) For the igneous rock, Elberton Granite, this was probably near the time of intrusion, and for the Lithonia Gneiss this was probably the time of granitization.

Rb-Sr and K-Ar Dates

Hadley (1964, fig. 4) has shown that the Rb-Sr and K-Ar dates in the central and southern Appalachians are concentrated in the times of the Acadian and Alleghanian (Woodward, 1957) orogenies, and he attributes the dates to cooling produced by these orogenic uplifts and subsequent erosion. Dates on Georgia minerals by the Rb-Sr and K-Ar methods show a cooling of the rocks over a vast period of time spanning the Acadian and Alleghanian orogenies. Dates are older (about 350 million years) on the northwest side of the State and younger (about 250 million years) on the southeast side of the crystallines (Pl. 1, in pocket). From the simplicity of the distribution of metamorphic isograds covering essentially all the crystallines of Georgia, it appears that there was a single period of metamorphism which produced the isograds. The uplift, erosion, and then cooling which set the isotopic dates of about 350-250 million years probably also set the isograds. There was probably less uplift on the northwest side, and the southeast side likely continued to rise after the northwest portion stabilized.

There are a few localities of metamorphic index minerals which are outside the zones as indicated on Plate 1 (in pocket): (1) In northern Columbia County in the portion of Plate 1 (in pocket) labeled "Areas of Low Grade Metamorphism" sillimanite has been reported by Crawford (1966 p. 17, 20, 25, and 32) and, McLemore (1965, map). This sillimanite may be due to local intrusions; however, there is not enough data within the area labeled "Areas of Low Grade Metamorphism" to delimit the regional metamorphic isograds which surely exist. (2) Hurst (1952, p. 98) states that sillimanite occasionally occurs in migmatites in northeastern Cobb County. (3) Kyanite occurs in association with sillimanite at several localities. The isograds were drawn at the first occurrence of the highest grade mineral in going toward higher grade; therefore, these kyanite occurrences were ignored when drawing the isograds.

Dates on Corbin Granite (Pl. 1, locality F-4) and Fort Mountain Gneiss (F-2) are the oldest mica dates and they are the furtherest west. At the points of collection of the samples, the biotite isograd is likely drawn slightly further west than it should be, because the biotite in these rocks may be Precambrian or Taconic biotite which has been heated slightly, but not recrystallized by the Paleozoic metamorphism, thereby resetting the dates to intermediate. These micas are at least as old as their respective dates: Fort Mountain Gneiss, 375 $\pm$ 20 million years, Middle or Late Devonian; and Corbin Granite, 430 $\pm$ 25 million years, late Middle Ordovician through the early part of the Silurian. These may be times of intrusion or metamorphism.

Recent Trends in the Application of Isotopic Dating

Most of the age determinations indicated above were carried out at a time when the major emphasis in isotopic geochronology was on reconnaissance studies aimed at determining the general age pattern of large regions. In more recent years the emphasis has shifted toward more detailed studies of smaller areas where the purpose is to complement structural and petrologic data in developing an understanding of tectonic processes. A very important consequence of this trend is that an isotopic age determined for an individual mineral sample is sometimes of little significance, but the interrelationships among the isotopic data from many samples may lead to very significant conclusions.

Because of the development of methods for interpreting the variation in isotopic data from different samples, many of the earlier problems of isotopic dating have been turned to advantage, particularly in studies of metamorphic rocks. For example, the possibility of loss of the daughter product(s) of radioactive decay has always been a serious problem when one is concerned with individual age measurements. When many samples, including different minerals, from within a single rock unit are analyzed, the pattern of daughter product loss can help establish the history of thermal and chemical processes which affected the rock after the minerals were formed.

Another example involves a problem which is perhaps not so generally appreciated as that of daughter product loss. This problem is the uncertainty in the isotopic composition of the daughter element incorporated in minerals at the time they are formed. The determination of an individual isotopic age requires three measurements:

1) the abundance of the parent element (from which the abundance of the radioactive parent isotope is calculated),
2) the abundance of the daughter element,
3) the isotopic composition of the daughter element.

A knowledge of the isotopic composition of the daughter element is required to determine what percentage of the element is not *radiogenic* (not produced by radioactive decay within a mineral, and hence not related to the age), but this percentage can be calculated only if the isotopic composition of the nonradiogenic portion is known (Fig. 1).

In potassium-argon work, the problem of the initial isotopic composition of argon is avoided by the normally (but not always) valid assumption that a mineral contains a negligible amount of argon at the outset. For U-Pb and Rb-Sr work, the problem has always been more serious, for "common" lead and strontium are incorporated in minerals when they form. It has long been recognized that common lead is widely variable in isotopic composition. Strontium is much less variable, but nevertheless the uncertainty in its composition has been a limiting factor in the reliability of individual Rb-Sr ages.

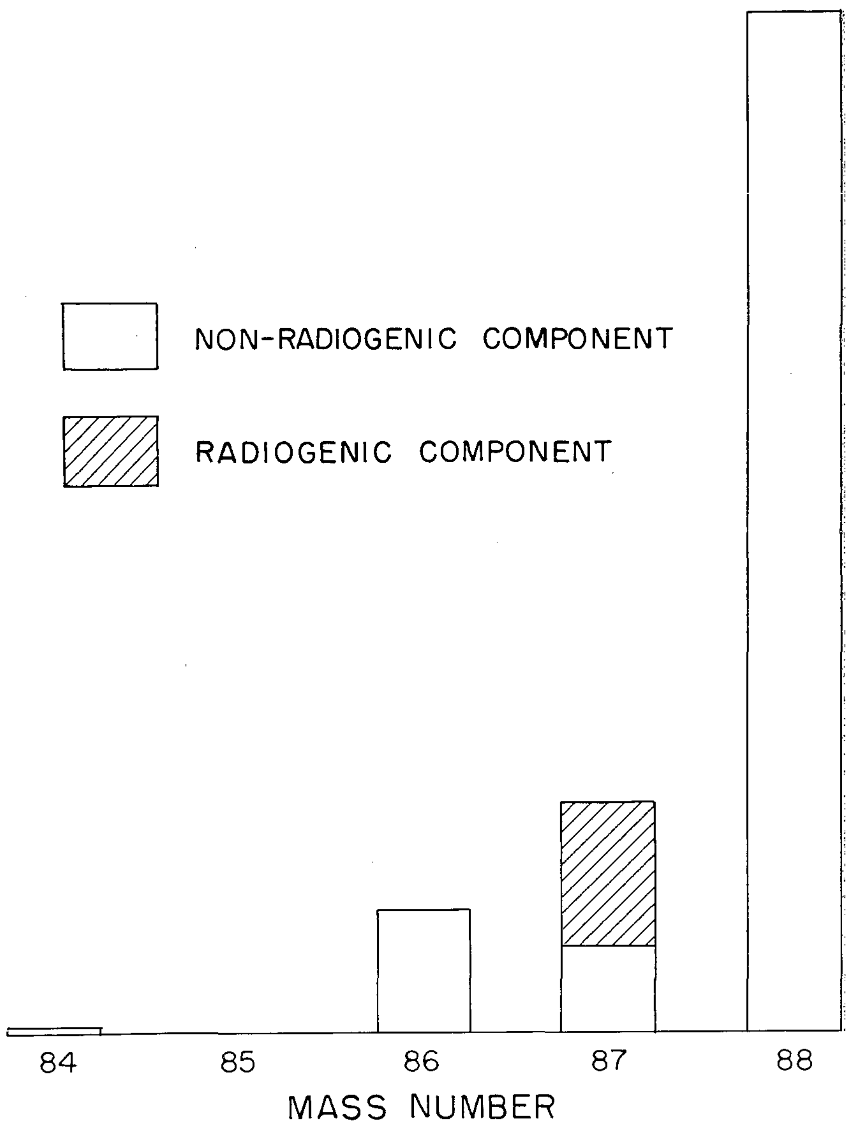

Figure 1—An illustration of the contributions of radiogenic and non-radiogenic strontium to the isotopic composition of strontium in a mineral. The proportion of Sr^{87} in the non-radiogenic portion is not fixed, but depends on the prior history of the materials from which the mineral formed.

Since about 1960 there has been a rapid increase in use of the Rb-Sr method, which has been brought about both by improved analytical precision and by recognition that the problem of initial strontium isotopic composition can be handled by analysis of multiple samples from the same rock unit. For metamorphic rocks, these techniques give not only a reliable age for the most recent cooling, but also allow one to "see through" the metamorphism to earlier events. Specifically, for alkali-rich rocks, the strontium isotopic composition of the rock as a whole is a key to the time of differentiation from a parent material less rich in alkalis.

These modern techniques of isotopic dating should prove to be of greatest value in studies of the Appalachians and other Paleozoic orogenic belts. Here the ages are sufficiently low that analytical errors will not likely obscure the sequence of events associated with orogeny, yet the activity is sufficiently old that extensive areas of the once deeply buried cores of the mountain ranges are now exposed.

The following paragraphs suggest the pattern of future application of isotopic dating to the crystalline rocks of Georgia. Only the three methods, K-Ar, Rb-Sr, and U-Pb, which have been of major importance in age studies of igneous and metamorphic rocks are considered. Rather than cite the large number of original papers which are pertinent to the discussion, we refer the reader to the comprehensive review by Hamilton (1965) and to a brief but critical review by Wetherill (1965).

Potassium-Argon Method

The analytical techniques for measurement of potassium and argon are relatively uncomplicated, and the choice of materials for analysis is somewhat less limited than for the other methods. Hence, K-Ar measurements should continue to be of widespread use in detailed geochronologic studies.

The most significant characteristic of the K-Ar system is the loss of argon, by thermal diffusion, from minerals at elevated temperatures. Fortunately, the rate of loss is somewhat different for different minerals, so the analysis of a variety of samples should provide details about the cooling histories of igneous rocks and of medium and high grade metamorphic rocks. In areas of low grade metamorphism, some minerals may retain argon which provides evidence of the origin or earlier history of the rocks, while other minerals may have argon which has accumulated only since metamorphism. The K-Ar relationships in such an area are likely to be very complex, but for this very reason it is in such areas that the method should ultimately prove to be of greatest usefulness.

In contrast to their sensitivity to thermal effects, K-Ar ages are often not seriously altered by weathering processes. Some of the detrital weathering products of crystalline rocks tend to retain the K-Ar age of the original rocks. This factor could be of importance in Georgia, where deep weathering is so common.

Materials:

The micas and hornblende are of greatest use in K-Ar work. These minerals retain argon quantitatively except at elevated temperatures. Biotite apparently begins to lose argon at somewhat lower temperatures than muscovite, and fine crystals lose argon more readily than coarse micas. Hornblende is more resistant to argon loss than the micas, and for this reason should be of great importance in future work in Georgia. Since the potassium content of hornblende is much lower than that of micas, larger samples are required for analysis, and greater attention to mineral purity is necessary.

Other materials which have been used in K-Ar work are the feldspars and whole-rock samples of fine-grained or glassy igneous rocks. K-feldspar has been noted for its lack of reliability because of argon loss at low temperatures. Nevertheless, the data from K-feldspar may be useful in detailed studies. Whole-rock K-Ar analyses have been quite useful for age studies of young volcanic rocks. Hopefully, the method can also be applied to fine-grained, post metamorphic intrusives in Georgia.

Rubidium-Strontium Method

Isotopic studies of Rb-Sr relationships are in many ways complementary to K-Ar studies. In simple circumstances, Rb-Sr age determinations provide an important check on K-Ar ages. Because of the geochemical similarity of K and Rb, the two methods may often be applied to the same minerals. Because of the gross differences in behavior between argon and strontium, geological processes which alter the apparent ages generally affect the K-Ar and Rb-Sr ages in different ways. Relative to argon, strontium is less sensitive to purely thermal effects, but strontium is more likely to be affected by base exchange or chemical weathering.

In contrast to the complete loss of argon during metamorphism, radiogenic strontium is frequently retained in rocks during the metamorphic process, though it may be re-distributed among the different minerals. As a result, a rock may retain information about its pre-metamorphic history. The time relationships of events prior to the most recent metamorphism are obtained by Rb-Sr analyses of different minerals within the rock and of whole-rock samples. Interpretation of such data requires a knowledge of the overall behavior of rubidium and strontium in a rock unit; so this type of isotopic work must be closely controlled by field and petrographic data.

Materials:

The slow rate of decay of Rb^{87} limits the Rb-Sr method to rocks in which rubidium has been considerably enriched. Hence, it is best suited to studies of felsic rocks. In a differentiated sequence of igneous rocks, the Rb-Sr relationships among the entire sequence may provide important information about the history of the rocks, provided the felsic materials were produced truly by differentiation with little contamination by alkali-rich materials from the country rock.

A variety of minerals may be involved in the Rb-Sr analysis of a rock, the most important being the micas and the feldspars. Loss of strontium from feldspar is not a problem as it is for argon.

Uranium-Lead Method

The usefulness of the U-Pb method is limited by the very low abundance of uranium and by its complex geochemical behavior. Furthermore, the complicated and energetic radioactive decay sequences of the uranium isotopes lead generally to partial loss of daughter products regardless of metamorphic effects.

Fortunately, there are two radioactive isotopes of uranium, with different decay rates, so that age relationships may be determined in spite of lead loss. It is also fortunate that zircon, one of the few common minerals with significant uranium content, is resistant to the effects of metamorphism. U-Pb analysis of zircon thus provides a straightforward way to "see through" metamorphism to earlier events, possibly even to the age of the source rocks for detrital zircons in metasediments. This is not to say that zircon is never affected by metamorphism. The age relationships may be altered by addition of material to older crystals and by the occurrence of more than one generation of zircons in a rock. Careful petrographic control is required for this type of work.

The U-Pb method has also been applied to monazite and more recently to sphene (Tilton and Grunenfelder, 1967). The latter may prove to be quite useful in age studies of Georgia rocks. One should also note the importance of analyses of "common" lead in K-feldspar. Although these do not yield isotopic ages, the relationships of the feldspar lead in different rocks of a region can provide important information about the genesis of different rock units, and thus be of considerable aid in the interpretation of isotopic ages.

Future Work

The crystallines of Georgia are at least as old as the isotopic dates (Paleozoic), and some rocks, metamorphosed and intruded during the Grenville orogenic cycle (about one billion years ago), likely extend into the Georgia crystallines from the northeast. Most geologists agree that much of the Piedmont of Georgia contains metamorphosed Paleozoic sediments. Drawing the boundary between these metamorphosed Paleozoic sediments and the Precambrian rocks may be possible using isotopic dating. This will not likely be possible with the K-Ar method, since both areas have been affected by Paleozoic regional metamorphism, but whole rock Rb-Sr analyses and U-Pb analyses of euhedral zircons may outline the Precambrian area.

Similar Rb-Sr and U-Pb dates on materials from metamorphosed extrusive rocks may lead to the establishment of a stratigraphic sequence applicable throughout much of the Georgia Piedmont. One should begin such a venture in the Little River ("Series") Group.

The Elberton Granite is an example of an intrusion which was likely intruded during the Taconic orogeny. There are probably many other igneous, and metamorphic, rocks which formed during this time interval which may be dateable by Rb-Sr or U-Pb methods. Intrusive rocks younger than the regional metamorphism may be dated by the K-Ar method, and in some cases by Rb-Sr and U-Pb methods, if appropriate materials are present. Examples of such intrusives are acidic dikes reported by many geologists and Triassic (?) diabase dikes.

Dietrich, Bottino, and Fullagar (1967) believe that some of the Appalachian faults may be dated by obtaining isotopic dates on the rocks in the fault zones. The Cartersville, Brevard, Goat Rock, and Towaliga are examples of faults along which the isotopic dates may have been reset by heat generated during faulting.

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[These dates were published in 1957 in the Geological Society of America Bulletin, vol. 68, no. 12, pt. 2, p. 1781. L. F. Herzog published this data in 1956 in Nuclear Science Series Report 19, p. 114-130 using a less acceptable Rubidium decay constant which gave different dates.]

F. New Georgia dates (See Table 1, p. 126).

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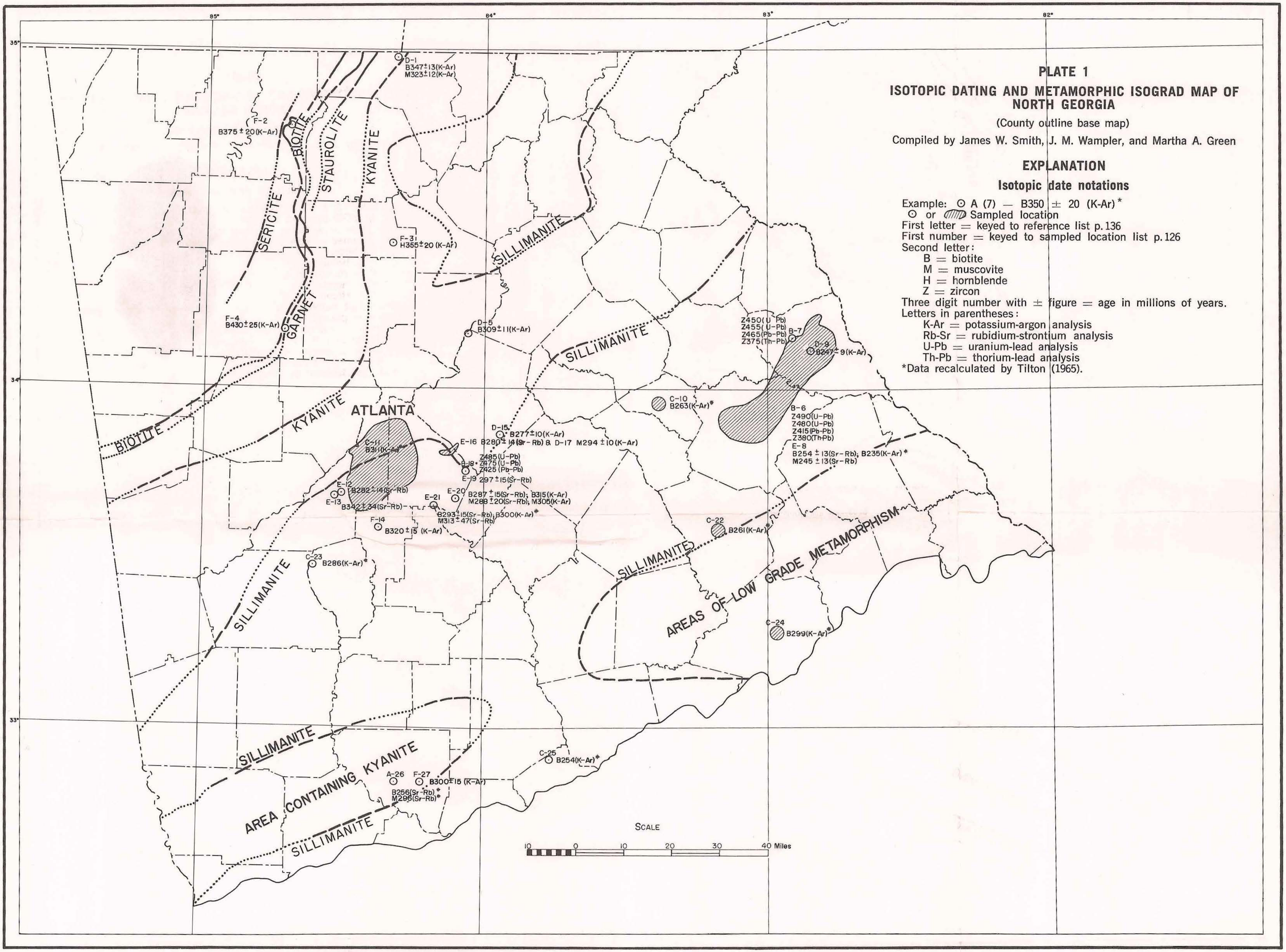


PLATE 1

ISOTOPIC DATING AND METAMORPHIC ISOGRAD MAP OF NORTH GEORGIA

(County outline base map)

Compiled by James W. Smith, J. M. Wampler, and Martha A. Green

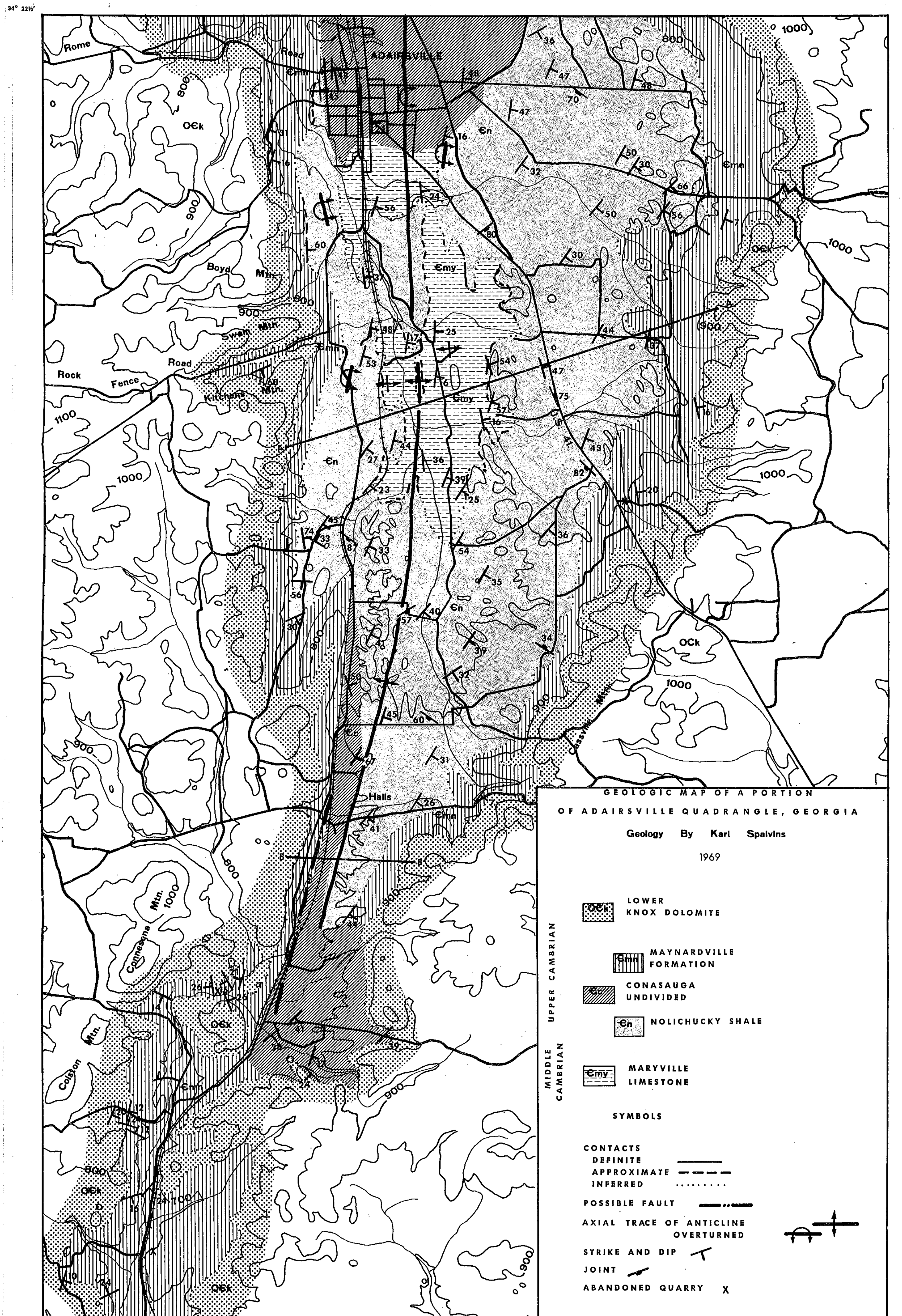
EXPLANATION

Isotopic date notations

Example: ⊙ A (7) — B350 ± 20 (K-Ar)*
⊙ or [hatched area] Sampled location
First letter = keyed to reference list p. 136
First number = keyed to sampled location list p. 126
Second letter:
- B = biotite
- M = muscovite
- H = hornblende
- Z = zircon

Three digit number with ± figure = age in millions of years.
Letters in parentheses:
- K-Ar = potassium-argon analysis
- Rb-Sr = rubidium-strontium analysis
- U-Pb = uranium-lead analysis
- Th-Pb = thorium-lead analysis

*Data recalculated by Tilton (1965).


34° 22½'
Rome
Road
ADAIRSVILLE
Boyd Mtn.
Swan Mtn.
Rock Fence Road
Kitchens Mtn.
U.S. 41
Halls
Connesena Mtn.
Colston Mtn.
Cassville Mtn.
34° 15'
84° 58' 15"
84° 52½'
GEOLOGIC MAP OF A PORTION
OF ADAIRSVILLE QUADRANGLE, GEORGIA
Geology By Karl Spalvins
1969
UPPER CAMBRIAN
MIDDLE CAMBRIAN
OЄk LOWER KNOX DOLOMITE
Єmn MAYNARDVILLE FORMATION
Єc CONASAUGA UNDIVIDED
Єn NOLICHUCKY SHALE
Єmy MARYVILLE LIMESTONE
SYMBOLS
CONTACTS
DEFINITE
APPROXIMATE
INFERRED
POSSIBLE FAULT
AXIAL TRACE OF ANTICLINE
OVERTURNED
STRIKE AND DIP
JOINT
ABANDONED QUARRY X
Contour Interval 100 Feet
1 1/2 0 1 mile
Scale
N
BASE MAP FROM USGS
ADAIRSVILLE, GEORGIA
15' QUADRANGLE
1944