GEORGIA
STATE DIVISION OF CONSERVATION

DEPARTMENT OF MINES, MINING AND GEOLOGY
A. S. FURCRON, Director
19 Hunter Street, Atlanta, Georgia

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THE MURPHY SYNCLINE IN THE TATE QUADRANGLE, GEORGIA

by

William M. Fairley

LETTER OF TRANSMITTAL

Department of Mines, Mining and Geology

April 15, 1965

His Excellency, Carl E. Sanders
Governor of Georgia and
Commissioner Ex-Officio
State Division of Conservation
Atlanta, Georgia

Dear Governor Sanders:

I have the honor to submit herewith Bulletin No. 75 of the Department of Mines, Mining and Geology, entitled "The Murphy Syncline in the Tate Quadrangle, Georgia" by Dr. William M. Fairley.

This is a technical bulletin prepared for geologists who are engaged in the exploration and discovery of marble deposits and in the structure and composition of the enclosing rocks which offer information regarding the deposits.

This geologic map and report changes appreciably the regional structural interpretation previously held for the area, particularly because it eliminates the Whitestone thrust fault, indicating that probably it does not exist.

The late cross-folding indicated on the geologic map may lead to the location of regional structures which control ore veins or other possible marble occurrences in the area.

Very respectfully yours,

A. S. Furcron

A. S. Furcron
Director

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

THE MURPHY SYNCLINE IN THE TATE QUADRANGLE, GEORGIA

By William M. Fairley

ABSTRACT

The Murphy Syncline in the Tate quadrangle of the Georgia Piedmont exposes 10,000 feet of metasediments. The Great Smoky, Nantahala, Brasstown, Murphy, Marble Hill and Andrews Formations were mapped in this structure. Facies changes from schist to marble and from graphitic to non-graphitic schist complicate the stratigraphy. Pegmatites and uralitized gabbro cut the metasedimentary rocks of the syncline.

The syncline is folded, overturned to the west, and shows an arcuate trend across the quadrangle. Oblique to the syncline are cross-folds with axes that plunge to the southeast. The largest cross-fold forms the east-west belt of marble between Tate and Marble Hill. Lineations of several kinds parallel the axes of the cross-folds. Joints lie in the "ac" plane of both the major fold and the largest of the cross-folds.

Most of the rocks of the Murphy Syncline within the quadrangle belong to the almandine amphibolite facies. Reconnaissance showed that the greenschist facies is developed to the west.

West of the Murphy Syncline is the Salem Church Anticline. The west limb of this anticline is the east limb of a large syncline mapped by Smith in the Waleska quadrangle.

INTRODUCTION

This paper concerns the commercially important "Georgia Marble" and the surrounding metamorphosed sedimentary rocks in the vicinity of Tate, Georgia.

Location of the area. The town of Tate in the Tate quadrangle is located 43 miles north of Atlanta (figure 1).

Topography. The Blue Ridge Mountains terminate in the northeast corner of the quadrangle; the remainder of the area is a plateau of low relief lying within the Piedmont Province. The topography is closely related to structure and to lithology. A group of isoclinally folded formations form the dominant structure which is generally, but not everywhere, emphasized by subsequent stream valleys (plate I). Linear marble belts lie in steep-walled valleys.

Field and laboratory methods. Aerial photographs at a scale of 1:12,000 supplied the base for detailed geologic mapping. Data collected during reconnaissance work in adjacent quadrangles were plotted on topographic and county road maps.

One hundred thirty-five thin sections were studied. Fabric studies of the deformation of the rocks were made and are reported in this paper.

Modal analyses, and the staining which was done in association with them, are after the method of Chayes (1949 and 1952).

Acknowledgements. The Georgia Department of Mines, Mining and Geology under the direction of Captain Garland Peyton sponsored the field work. Drs. A. S. Furcron and V. J. Hurst introduced me to the area and offered helpful suggestions on mapping methods. Mr. Robert Bentley was very helpful in preparing the manuscript and maps for publication. Mr. J. W. Dent, President of the Georgia Marble Company, and other officials of the Company granted access to mines and quarries and permitted the use of core drill records. I am grateful to The Johns Hopkins University for financial assistance while I was a student there and to the staff of the Geology Department for advice and criticism in preparing this work as a doctoral dissertation. I acknowledge particularly my wife, Dolores, without whose constant encouragement the manuscript could never have been completed.

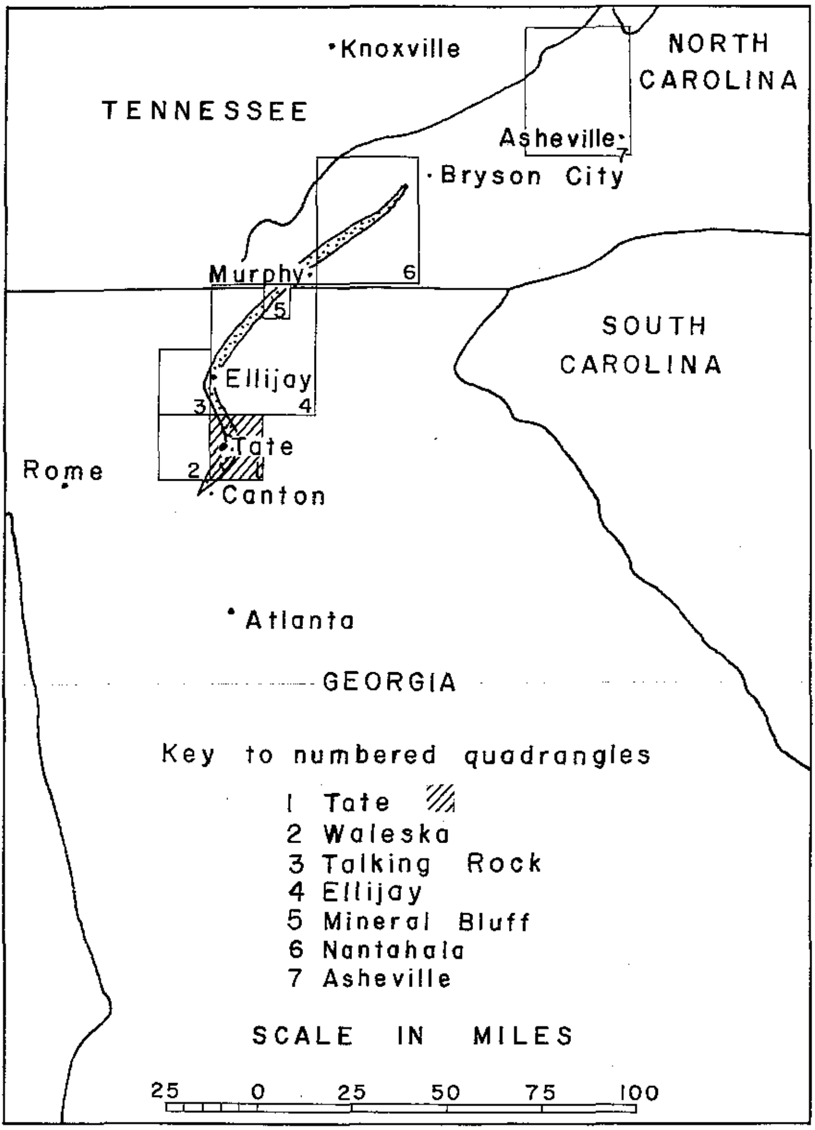

Fig. 1. Index map showing the location of the Tate and other quadrangles. The stippled area shows the location of the Murphy Marble and the formations adjacent to it.

EARLY GEOLOGIC INVESTIGATIONS

W. S. Bayley began mapping the Tate quadrangle in 1925. He adopted many of the stratigraphic and structural units used by LaForge and Phalen (1913) in the Ellijay quadrangle to the north (figure 1). LaForge and Phalen had in turn adopted the units used by Keith (1907) in the Nantahala and other quadrangles of North Carolina. (A correlation chart showing the stratigraphic units is given in table 1). This uniformity of nomenclature made it possible to give a connected interpretation of the geologic structure over a large segment of the Piedmont in the Southern Appalachian Mountains.

The early workers had traced a syncline from Bryson City, North Carolina, southwestward for about one hundred and twenty-five miles to the southern end of the Tate quadrangle. It was named the Murphy Syncline for its prominent marble deposits near Murphy, North Carolina. The syncline was thought to be an isoclinal fold, overturned to the west, and with part of its eastern limb cut out by a fault called the Whitestone thrust. This general interpretation has stood the test of time, but with considerable modification. One important modification that the present author has made is to eliminate the Whitestone thrust fault in the Tate quadrangle.

Keith Nantahala Folio 1907	LaForge & Phalen Ellijay Folio 1913	Hurst Mineral Bluff Quad. 1955	Bayley Tate Quad. 1928	Fairley Tate Quad. 1962
		Mineral Bluff Fm.		
Nottely Quartzite	Nottely Quartzite	Nottely Quartzite		
Andrews Schist	Andrews Schist	Andrews Schist		Andrews Schist Marble Hill Schist
Murphy Marble	Murphy Marble	Murphy Marble	Murphy Marble	Murphy Marble
Valleytown Fm.	Valleytown Fm.	Brasstown Fm.	Valleytown Fm.	Brasstown Fm.
Brasstown Fm.	Brasstown Fm.			
Tusquitee Quartzite	Tusquitee Quartzite	Tusquitee Quartzite		
Nantahala Slate	Nantahala Slate	Nantahala Slate	Nantahala Schist	Nantahala Schist
Great Smoky Conglomerate	Great Smoky Formation	Great Smoky Group: Dean Fm.	Great Smoky Formation	Great Smoky Formation
		Great Smoky Group: Hothouse Fm.		
		Great Smoky Group: Hughes Gap Fm.		
		Great Smoky Group: Copperhill Fm.		
Hiwassee Slate			Hiwassee Schist	Hiwassee-Canton Schist
Carolina and Roan Gneiss			Carolina and Roan Gneiss	

Table 1. Correlation chart of Southern Appalachian Formations.

The Problem of the Whitestone Thrust

The Whitestone thrust was introduced by LaForge and Phalen to explain the presence of graphitic schist above and to the east of the marble at Whitestone, Georgia (figure 2). It was customary at that time to correlate every schist in the upper part of the syncline with the Nantahala Schist. If the Nantahala

Schist was above the Murphy Marble on the overturned limb of the syncline, then a thrust fault was required to cut out the Valleytown Formation. Actually, no physical evidence of faulting was found at Whitestone; the upper part of the marble is

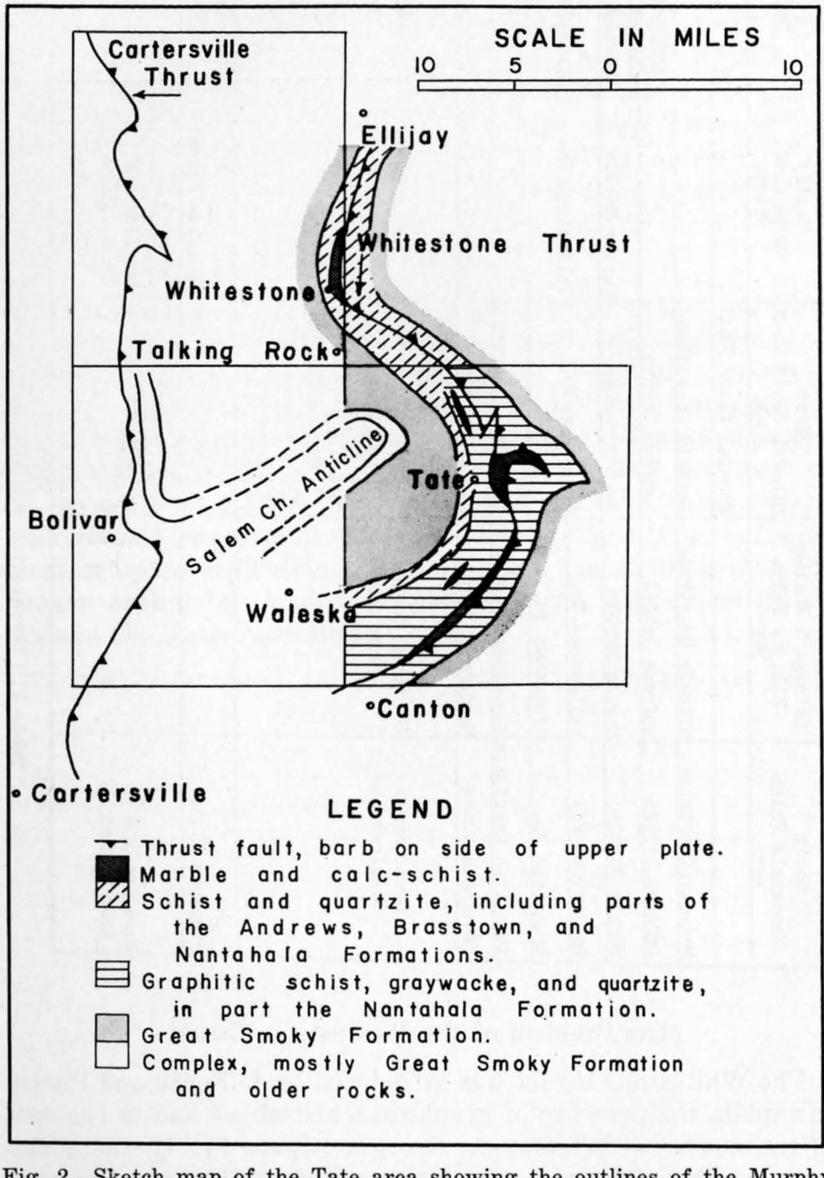

Fig. 2. Sketch map of the Tate area showing the outlines of the Murphy Syncline and the Salem Church Anticline. The Whitestone thrust is shown as mapped by LaForge and Phalen (1913) and Bayley (1928).

graphitic, and probably grades into the overlying schist. Recent mapping by Power and Reade (1962, p. 9) bear this out, although they found faults other than the trust at Whitestone. Bayley, (1928, p. 122) admitted that there is no direct evidence for the thrust, but he considered its presence necessary to explain puzzling outcrop patterns, especially in the northern part of the quadrangle.

Bayley's interpretations. Bayley traced belts of the Great Smoky, Nantahala, and Valleytown Formations without difficulty from the southern part of the Ellijay quadrangle through the western part of the Tate quadrangle (figure 3). The small area of Great Smoky rocks in the north central part of the quadrangle caused him trouble because he could not distinguish the Great Smoky Formation from the adjacent Carolina Gneiss. He said (p. 56), ". . . as there seems to be no way of distinguishing between the rocks belonging in the Great Smoky formation and those belonging in the Carolina formation, the boundary between the two formations must be drawn arbitrarily in such a position as will express a reasonable interpretation of the geologic structure." Bayley (p. 61) also found the Nantahala Formation on the eastern limb of the syncline troublesome because he could not trace it southward through the quadrangle. Bayley eliminated these problems by shifting the Whitestone thrust to the east, thus cutting out the Great Smoky and Nantahala Formations in the north central part of the quadrangle.

Bayley considered that the thrust was displaced by a normal fault in the southern part of the north central rectangle of the Tate quadrangle. The displacement by normal faulting was supposed essential to avoid a distinctive garnet-mica-schist which lay athwart the trend of the thrust, and which otherwise would have been cut into two parts of different ages on opposite sides of the thrust. The thrust is then brought all the way around the sickle-shaped marble body, making a partial fenster. Between this marble and the long, thin marble belt to the south, the position of the thrust is shown as inferred, because the rocks on both sides of the thrust are identical. An additional thrust was required to explain the presence of marble in the Carolina Gneiss in the southeast part of the central rectangle. There are thin graphitic schists along the eastern margin of the elongated marble belt in the central and southern part of the quadrangle. These, like the graphitic schists at Whitestone, were assigned to the Nantahala Formation. The sequence, Murphy Marble,

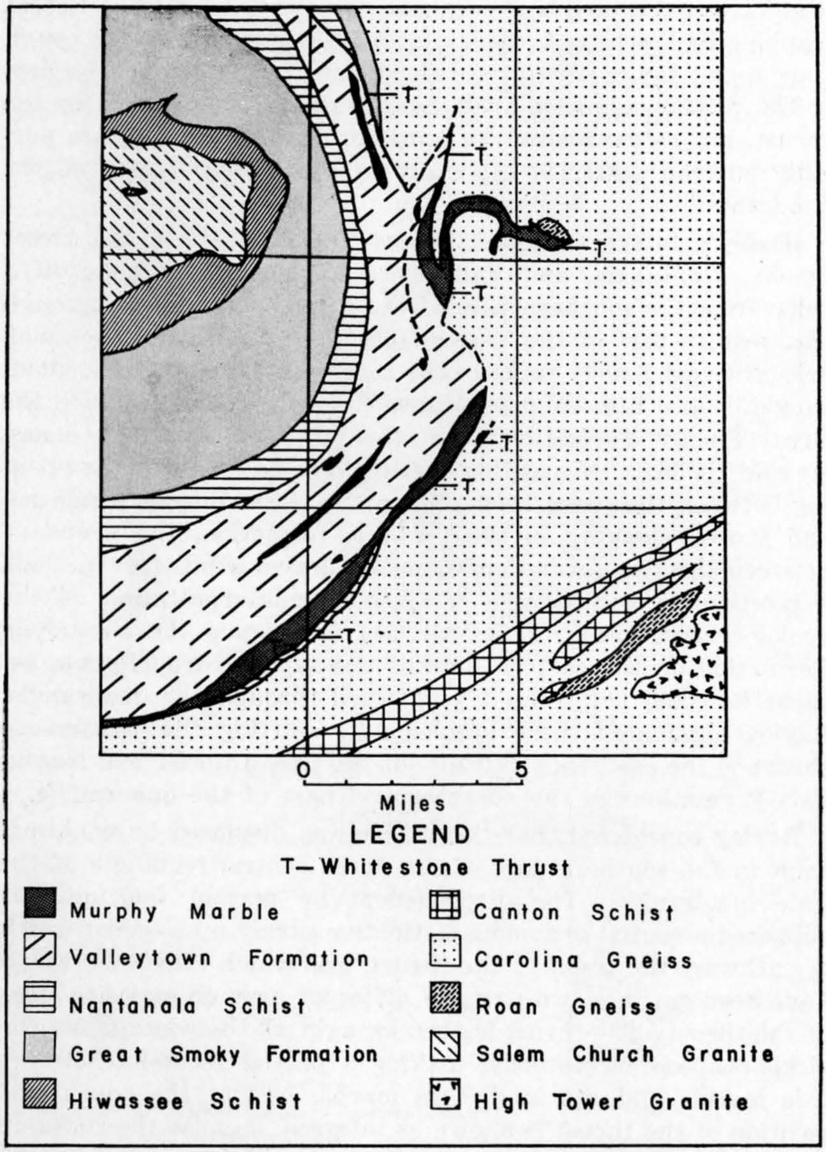

Fig. 3. Geologic map of the Tate quadrangle, after Bayley.

Nantahala Schist, Carolina Gneiss, required two thrusts to cut out the Valleytown and Great Smoky Formations (table 1). The supposed thrust bifurcates to enclose the graphitic schists and unites again at the southwestern edge of the quadrangle.

Revised Interpretations Based on the Present Work

These structural complications invited closer study, and so the area was remapped in greater detail. The first step was to establish the stratigraphic succession as closely as exposures permitted. It soon became evident (see Plate 1) that a sequence of repeated lithologies was characteristic of the stratigraphy in the central part of the quadrangle. When this pattern of repeated lithologies began to develop in the early stages of the mapping, the author formed doubts about the presence of the Whitestone thrust, and wondered if the major structure was truly a syncline or perhaps an anticline. Top-bottom criteria are not well developed in the Tate quadrangle, and so it was necessary to correlate the stratigraphy with areas where the sequence is positively known. The nearest mapped area with a well-documented stratigraphic sequence was the Mineral Bluff quadrangle (Hurst, 1955). The author then traced conglomerates at the top of Hurst's Dean Formation (Great Smoky Group, table 1) on the west limb of the Murphy Syncline from the Mineral Bluff quadrangle to the Tate quadrangle, making use of work done on these conglomerates by Nuttall (1951). Also, the top of the Great Smoky Group on the east limb of the syncline was traced. However, the conglomerates are not as thick, coarse, or extensive on the east limb of the syncline as on the west limb and thus the correlation between the Mineral Bluff and the Tate quadrangles along this limb was harder to make. Later, it was found that the west limb of the Murphy Syncline is the east limb of the Salem Church Anticline (figure 2), and that the west limb of the anticline is the east limb of a syncline whose west limb was mapped by Smith (1959). Smith had numerous top-bottom criteria in his area to document his stratigraphic sequence.

Therefore it is clear that the rocks of the Tate area do indeed belong to the Murphy Syncline and that this fold is one of several large folds in the Georgia Piedmont. The new mapping shows that in the Tate quadrangle the Murphy Syncline is composed of approximately 10,000 feet of metasediments belonging to the almandine amphibolite facies. The original sediments were silts, sands, and carbonates which were poorly sorted both texturally and mineralogically, and the lithologies grade into each other both laterally and vertically. Bedding has persisted through metamorphism; grading is still visible at a few localities, but most sedimentary structures have been obliterated.

The curving trend of the Murphy Syncline is striking. Marbles and other rocks are folded along axes which enter the quadrangle at the northwest, curve through its east central part, and leave at the southwest. These folds are overturned to the west, but the trend is interrupted by cross-folding east of Tate.

No evidence for the Whitestone thrust can be found in the Tate quadrangle. Because the new stratigraphic work brought forth evidence of repeated lithologies, this fault is no longer needed to explain the geology, and at several localities where it was mapped, the contacts are normal, gradational sedimentary contacts (pages 17 and 37 to 39).

Changes in stratigraphic nomenclature. The term "Valleytown Formation" has been discarded in favor of "Brasstown Formation" in keeping with the current practice of the Georgia Geological Survey for the reasons given on page 19.

The Carolina Gneiss has been subdivided, and as suspected by Bayley, much of it belongs to the Great Smoky Formation. All the remainder of the gneiss has been mapped with the Brasstown and Andrews Formations, and no Carolina Gneiss appears on the map. This subdivision of the Carolina Gneiss indicated that the small body of marble in the southeast part of the central rectangle lies above the Brasstown Formation at the proper stratigraphic position of the Murphy Marble, and no thrust fault is required to explain its presence.

The Nantahala Schist does not occur along most of the eastern limb of the syncline within the area of the map. Facies changes, combined with non-deposition, are believed to account for its absence (page 18).

THE STRATIGRAPHIC SEQUENCE

General remarks. The formation names are modified from those of Hurst (1955) who, with some modifications, adapted his from Keith (1907) and from LaForge and Phalen (1913). A correlation chart is given in table 1.

The Canton and Hiwassee Schists may lie beneath the Murphy Syncline in the Tate quadrangle (see discussion of reconnaissance work, page 63) but, the Great Smoky Formation is the oldest formation known with certainty to have been folded into this syncline.

Age. The age of the rocks in the Murphy Syncline is not known, and no additional evidence as to their age was obtained during this work. Hurst (1955, p. 8) and King et. al. (1958, p. 965) have suggested that the Great Smoky Formation is Precambrian and that the Nantahala Formation and younger rocks are Early Paleozoic.

The Great Smoky Formation

Name and correlation. Keith first published the stratigraphic term "Great Smoky conglomerate" in his description of the Asheville (1904) and Nantahala (1907) quadrangles. Included with the conglomerates are sandstone, quartzite, graywacke, mica schist, garnet schist and slate. LaForge and Phalen (1913) traced these rocks into the Ellijay quadrangle and called them the "Great Smoky formation." Hurst (1955) and King, et. al, (1958) called the Great Smoky a group, subdividing it into several formations, but King did not use the same names nor correlate his formations with Hurst's. The term Great Smoky Formation is retained for the Tate quadrangle because poor exposure does not permit subdivision.

Distribution. The Great Smoky Formation crops out along two broad belts within the Tate quadrangle (Plate 1). These belts can be traced northward into the Nantahala quadrangle, thus allowing correlation of structures and stratigraphy from one quadrangle to another.

Megascopic description. The Great Smoky Formation in the Tate quadrangle consists of interbedded schist, metagraywacke, and a few quartzites. These rocks grade into one another without sharp contacts. The schists average ten to twenty feet thick and the metagraywackes thirty to forty feet. The greatest thickness observed of either rock type was approximately one hundred feet.

Original bedding can be recognized in the Great Smoky Formation, and in most of the younger rocks, by inter-layering of schists with metagraywackes or quartzites.

The metagraywackes are fine- to medium-grained gray rocks consisting mostly of quartz and feldspar with abundant biotite and muscovite. These micas produce a weak schistosity in the rock.

The schists are coarse-grained and contained abundant muscovite with quartz, feldspar and small amounts of biotite. Dodecahedral garnet porphyroblasts 1-3 millimeters in diameter are common in some of the layers. With an increase in the amount of quartz and feldspar, the schists grade into metagraywacke.

The thickness of the formation cannot be determined accurately because of possible repetition of strata by small scale folding. The outcrop width of the formation also varies greatly, due possibly to original conditions of sedimentation and to tectonic thinning. Assuming no repetition by small scale folding within the limbs of the syncline, the formation is at least 5,000 feet thick at its area of narrowest outcrop within the western belt. The southernmost portion of the eastern belt may be somewhat thinner (Plate 1).

Microscopic description. Quartz is an abundant constituent in both the metagraywacke and schist. Undulatory extinction and fine hair-like fractures are common. The grains are anhedral, and equidimensional to slightly elongated. The elongated grains contribute to the schistosity outlined by micas. Clastic outlines of quartz grains were not found in the Tate quadrangle, but to the north they are common, especially in conglomerates (Hurst, 1955, p. 14).

Plagioclase, both twinned and untwinned, occurs in shapeless to slightly elongated grains. All of the compositions determined were within the range of oligoclase. However, results on the untwinned grains are based only on 2V measurements, and these are not reliable for precise composition determinations. Some oligoclase grains show sericitization along alternate twin lamellae, but in others sericitization seems to have no relation to the twins. Much of the oligoclase is clear and colorless; untwinned grains are difficult to distinguish from quartz. Some quartz grains are clouded with inclusions too small to be identified, and this makes the problem of distinguishing quartz from oligoclase more difficult. Potash feldspar was not observed in either stained or unstained thin sections.

Biotite, commonly with ragged sides and terminations, averages about one-half millimeter long. Its pleochroism ranges from pale olive or yellowish gray to grayish brown or moderate brown. Dark reddish brown biotite, typical of rocks stratigraphically higher in the syncline, is rare. Pleochroic haloes up to one-quarter millimeter in diameter enclose zircon.

Muscovite in places is 1½ millimeters long and is typically larger than biotite. Both muscovite and biotite lie in the foliation planes and only rarely does a grain lie across the foliation except in areas of cross-folding. The biotite greatly exceeds muscovite in the metagraywackes (modes 2, 3, and 4 of table 2). Biotite and muscovite occur in nearly equal quantities where metagraywacke grades into mica schist (mode 1 of table 2). The mica schists consist predominantly of muscovite; they are difficult to sample in the field because they crumble easily, and few thin sections have been cut from them.

Garnet is a common minor mineral in the schists but is rare in the metagraywacke. Spongy porphyroblasts of garnet up to three millimeters in diameter, with areas around them cleared of mica, indicate that the garnet contains constituents that in other parts of the rocks enter mica.

A few zoned tourmalines one-eighth to one-half millimeter in diameter were seen in almost every thin section.

Minor chlorite replaces the edges of biotite grains and partially pseudomorphs garnet crystals. This is apparently a minor retrogressive effect.

Opaques include small amounts of pyrite, graphite and ilmenite with thin, cloudy, highly birefringent rims surrounding the ilmenite. The biotite of this ilmenite-bearing rock has a slightly reddish-brown pleochroism.

Kyanite is found in both limbs of the syncline, but is more common in the eastern limb where it forms anhedral replace-

TABLE 2

MODAL ANALYSES OF ROCKS FROM THE GREAT SMOKY, NANTAHALA & BRASSTOWN FORMATIONS

	1	2	3	4	5	6	7	8	9	10	11	12	13
Quartz	31	52	50	52	48	20	68	72	73	34	59	44	42
Oligoclase	8	18	18	26	27	7	15	8	3	15	1	2	12
Biotite	33	19	28	16	22	9	15	14	10	15	19	6	26
Muscovite	25	5	4	1		44	1	4	12	29	19	43	20
Garnet		4	Tr	4	Tr	6				6		Tr	
Opaque	2	1	Tr	1	3	2	1	1	1	2	1	4	1
Chlorite		Tr			Tr				2			1	
Zircon	Tr					Tr					Tr		Tr
Sphene	Tr											Tr	
Tourmaline		Tr			Tr	Tr	Tr	Tr		Tr	Tr		Tr
Staurolite						12							
Calcite											1		
Clinozoisite											Tr		

Modal analyses in volume percentage rounded off to nearest percent.

1. Great Smoky micaceous metagraywacke, western limb of syncline, near Bethany Church.

2. Great Smoky metagraywacke, western limb of syncline, one mile east of Bethany Church.

3. Great Smoky metagraywacke, eastern limb of syncline, 2½ miles north of Holcomb.

4. Great Smoky metagraywacke, eastern limb of syncline, 2 miles southeast of the Harrington quarry (see figure 4).

5. Nantahala Formation micaceous metagraywacke, one mile west of Fairview Church.

6. Nantahala Formation staurolite schist, near base of formation on Sharp Mountain Creek.

7. Nantahala Formation feldspathic quartzite, 2¼ miles southwest of Fairview Church.

8. Nantahala Formation biotite quartzite, 1.8 miles southwest of Fairview Church.

9. Quartzite from Tate flagstone quarry.

10. Quartz schist, one-half mile northeast of Marble Hill.

11. Micaceous quartzite from a flagstone quarry two miles southeast of Jasper.

12. Quartz schist, 2½ miles north of the Cherokee quarry.

13. Quartz schist, from a flagstone quarry one mile northwest of Long Swamp Church.

ments of muscovite and also occurs as irregular porphyroblasts. Kyanite is common in rocks east of the Tate quadrangle (see Furcron and Teague, 1945, especially pages 30-35).

Original conditions of sedimentation. Pettijohn (1957, p. 308) pointed out the typical association of graywacke and shales. He also summarized the arguments to show that graywackes are "the earmark of sedimentation in tectonically unstable regions especially in eugeosynclinal belts." (ibid. p. 313).

The graywackes of the Great Smoky Formation show most of the typical characteristics of graywacke such as poor compositional sorting, association with shales, and graded bedding. Lavas, also commonly associated with graywackes, occur south of the Tate quadrangle in rocks which reconnaissance work suggests belong to the Great Smoky Formation. Typically graywackes consist of quartz, feldspar and rock fragments in a sericite-chlorite matrix. Rock fragments are not present in the graywackes of the Murphy Syncline of the Tate quadrangle, but they do occur in the coarser rocks just to the north. The fine-grained matrix materials have recrystallized to mica.

The graywacke-shale association is the antithesis of the orthoquartzite-carbonate association. The latter is indicative of quiet tectonic conditions under which the sediments have time to reach maturity (texturally and compositionally) before burial. The younger sedimentary rocks of the Murphy Syncline tend to be better sorted than the Great Smoky graywackes, but the orthoquartzite-carbonate association does not occur in the Tate quadrangle. Some data on the changing trends of the sedimentary associations are given in the discussion of the Nantahala Formation below. The sediments of the Murphy Syncline in the Tate quadrangle appear to represent sedimentation from one tectonic episode; the coarser, poorly sorted sediments occur in the lower part of the syncline; the finer, better sorted sediments occur in the upper part of the syncline.

The Nantahala Formation

Name and correlation. Keith (1904, 1907) mapped a group of mica schists and ottrelite schists in the Asheville and Nantahala quadrangles, and named them the Nantahala Formation. LaForge and Phalen (1913), and Bayley (1928), mapped the extension of this formation through the Ellijay and Tate quadrangles.

Megascopic description. The Nantahala Formation in the Tate quadrangle consists of graphitic schist interbedded with metagraywacke and feldspathic quartzite. Metagraywackes are found mostly near the base of the formation and quartzite near the top. Both the metagraywacke and quartzite are sporadically graphitic. The quartzite is micaceous; like flagstone it splits into layers a few millimeters to two or three centimenters thick along the micaceous partings. The schists are composed mainly of quartz and muscovite, and resemble schists of the Great Smoky Formation except that they are dark blue to black because of disseminated graphite. Near the base of the Nantahala Formation staurolite porphyroblasts up to five centimeters long are locally abundant. (See modal analysis number 6 of table 2). The basal beds contain a few scattered quartz and feldspar pebbles. Feeble grading of pebble sizes suggests that the beds are right side up. The conglomeratic graywackes and staurolite schists are better developed to the north and are probably equivalent to the Dean Formation as mapped by Hurst (1955). Garnets, one to three centimeters in diameter, occur in minor quantities in the schists.

Estimates of the thickness of the formation are subject to the same uncertainties as the estimates for the Great Smoky Formation, but the Nantahala Formation is probably about 1300 feet thick.

Contact relationships. The upper beds of the Great Smoky Formation and the lower beds of the Nantahala Formation both consist of schist and metagraywacke. The contact between the formations is drawn so as to include the distinctly dark colored (graphitic) schists in the Nantahala Formation. Two features, the thickness of the interbedded units, and the quartz to feldspar ratio, are gradational across the contact. The average thickness of the interbedded schist and graywacke units decreases, although irregularly, from about thirty feet in the middle of the Great Smoky Formation to about five feet in the middle of the Nantahala Formation. The quartz to feldspar ratio increases irregularly through the stratigraphic section from the Great Smoky Formation to the Andrews Formation. The quartz to feldspar ratio is higher in the younger beds on both limbs of the syncline and both limbs belong to the same metamorphic facies. The ratios then must reflect original compositional differences in the sediments even though some of the feldspar may be of metamorphic origin.

The upper beds of the Nantahala Formation and the lower beds of the overlying Brasstown Formation consist of schist and quartzite. The contact is drawn to include the distinctly graphitic schists in the Nantahala Formation.

Distribution. The Nantahala Formation on the west limb of the syncline follows a clearly defined arcuate trend (Plate 1).

It is not possible to map the Nantahala Formation on the east limb of the syncline south of the Ellijay quadrangle. As the eastern belt of the Nantahala Formation is traced from the south end of the Ellijay quadrangle into the northern end of the Tate quadrangle the graphite content of the rocks gradually diminishes, and the width of the belt between the Great Smoky and Andrews Formations gradually decreases. The diminution of the width of this belt is not very evident in the northern half of the quadrangle because of the cross-folding east of Tate, but from Ball Ground southward the reduced thickness is obvious. The decrease in the graphite content of the schists and the diminution of the width of the formation southward, suggest that a facies change combined with non-deposition may account for the absence of the Nantahala Formation along the east limb of the syncline.

Microscopic description. Quartz and feldspar in anhedral, slightly elongated grains are the chief constituents of the metagraywacke. The feldspar is clear, colorless oligoclase, both twinned and untwinned. Potash feldspar was not detected either microscopically or by staining. Biotite is the common mica in the metagraywacke, but muscovite is common in the schists (contrast modes 5 and 6 of table 2).

The schists are composed of coarse folia of muscovite "dusted" with fine opaque matter, both graphite and pyrite. An analysis published by Bayley (1928, p. 64) showed 4.5% loss on ignition, presumably largely carbon. Between the mica folia are quartz-oligoclase lenses a few millimeters wide and one or two millimeters thick. Staurolite, in the few places where it occurs, is very spongy, poikilitically enclosing muscovite, biotite, garnet and numerous grains of quartz. Biotite porphyroblasts 3-4 millimeters long are present in the rocks containing staurolite. In the biotites as many as 40-50 tiny grains of zircon occur, each surrounded by a blackened halo.

The Brasstown Formation

Name and correlation. In the northern part of the Ellijay quadrangle LaForge and Phalen (1913) mapped three formations between the Nantahala and Murphy Formations. Later workers recognized only two formations, the Tusquittee Quartzite and the Brasstown Formation. The third, the Valleytown Formation, was thought by Furcron and Teague (1945, p. 39) to be an assemblage of rocks which really belong to other formations. Hurst in his detailed mapping of the Mineral Bluff quadrangle assigned the rocks of the Valleytown Formation to the Brasstown, Andrews, Nottely and Mineral Bluff Formations. The designation "Valleytown Formation" has been dropped from the stratigraphic terminology used in the Georgia Piedmont.

The Tusquittee Quartzite is thin and does not extend into the southern part of the Ellijay quadrangle. Only the Brasstown Formation lies between the Nantahala and Murphy Formations in the Tate quadrangle.

Distribution. The Brasstown Formation occupies several belts in the central part of the quadrangle (Plate I). The repetition of the formation is due to folding, and the distribution of the anticlines and synclines that bring about this repetition is shown on the cross-section of figure 5.

Megascopic description. The Brasstown Formation consists of about 1,500 feet of fine- to medium-grained micaceous quartzites interbedded with muscovite schist. The interbedded units are generally only a few inches thick and do not exceed two or three feet. The quartzites are gray, with numerous micaceous partings which cause the rock to break into slabs, approximately one-quarter to one inch in thickness. The thicker slabs are used as flagstone. The muscovite schists are silvery, coarse-grained, and generally contain much quartz. In places this schist contains a few garnets but they are only one to two millimeters in diameter in contrast to the large garnets of the overlying Andrews Schist. Graphite occurs locally in the Brasstown schists; it is abundant in the northernmost portion of the Tate quadrangle and in the southern part of the Ellijay quadrangle. Oligoclase is common in a few schists and quartzites, especially in the area east of Tate.

Microscopic description. Quartz occurs as equant to slightly elongated granoblastic to slightly sutured grains. Most grains

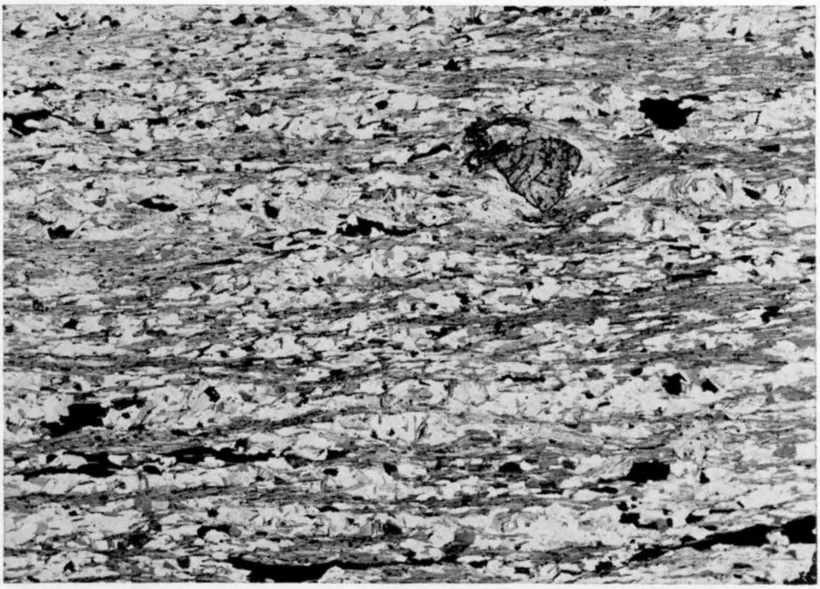

Fig. 1. Typical quartz-mica schist of the Brasstown Formation. The single large grain is garnet, the black grains are pyrite. Branch of Long Swamp Creek two and one half miles north of the Cherokee quarry. Photomicrograph, partly crossed nicols, X9.

Fig. 2. Thin mylonitized zones (above) and large fractured muscovite grains (below). The dust-like needles in the muscovite are kyanite. On the East Branch of Long Swamp Creek, northeast of the Cowart quarry. Photomicrograph, partly crossed nicols, X9.

PLATE 2

are 1/4 to 1/8 millimeter in diameter, some show undulatory extinction, and a few are clouded with sericite inclusions.

Oligoclase is the only feldspar present, except near the contact with the overlying marble where more calcic plagioclases are found. The oligoclase is generally clear and colorless, but in places has sericite inclusions.

Biotite is the more common mica in the quartzites, but muscovite predominates in the schists. Both micas are nearly always present. Individual grains of mica in the quartzites generally do not exceed 1/4 millimeter in length, but in more schistose rocks the grains are matted together in little lenses less than a millimeter thick and five to ten millimeters long (Pl. 2, Fig. 1). Muscovite grains up to one centimeter in diameter are common in the foliation planes of the schists.

Garnet porphyroblasts up to one millimeter in diameter warp the foliation (Pl. 2, Fig. 1). Most are sieved with abundant inclusions of quartz. A few zoned tourmaline grains are seen in most thin sections. Chlorite occurs sparsely as pseudomorphs of garnet and along the cleavage plates of biotite. Kyanite is common east of Marble Hill in the Brasstown Formation. It occurs in acicular grains or clusters of grains sprinkled through muscovite (Pl. 2, Fig. 2). Furcron and Teague (1945) have described kyanite occurrences in the Tate and adjacent areas. Calcite is rare in the Brasstown Formation except near the overlying marble (see the discussion of the contact relationships).

The texture of the rocks that compose the Brasstown Formation changes in the vicinity of Marble Hill and eastward. The smooth foliation (Pl. 2, Fig. 1) that prevails in most of the Brasstown Formation is thrown into crenulations and small folds, and various amounts of crushing are apparent in the rocks. Cataclastic textures occur in the easternmost exposures of the Brasstown Formation east of Marble Hill and contain thin lenses and bifurcating stringers of crushed quartz with wisps and shreds of muscovite and kyanite. Lenses of coarse quartz up to about one millimeter wide lie between these crushed lenses. Weakly developed crushed zones can be seen in plate 2, figure 2, above the large muscovite grain which is fractured but not strongly sheared. This rock consists of somewhat less than fifty percent aphanitic paste and is a "protomylonite" as defined by Hsu (1955, p. 252). Large relic muscovite grains partially crushed

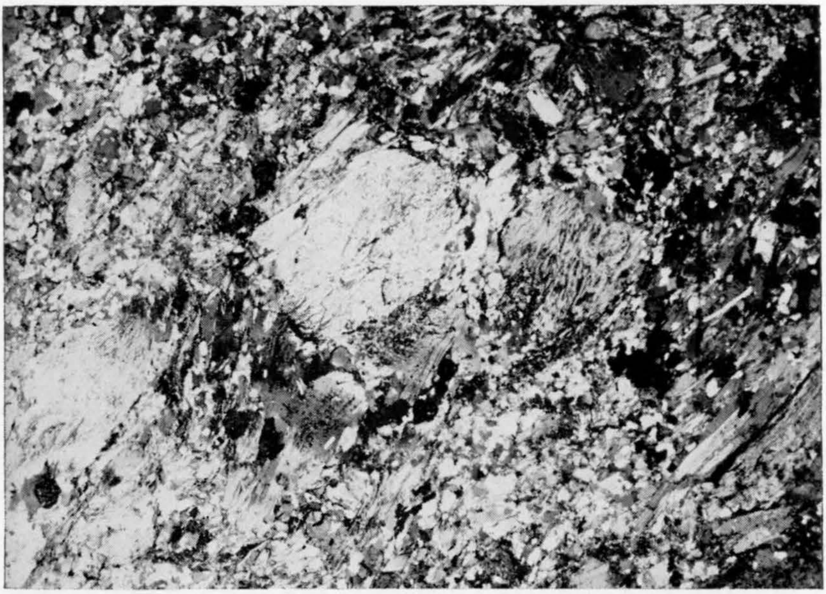

Fig 1. Sheared relics of muscovite. Note the two large grains in the upper center of the photograph. The grain to the right has nearly lost its identity by being smeared along the foliation. From the hillside at the south end of the Cowart quarry. Photomicrograph, partly crossed nicols, X10.

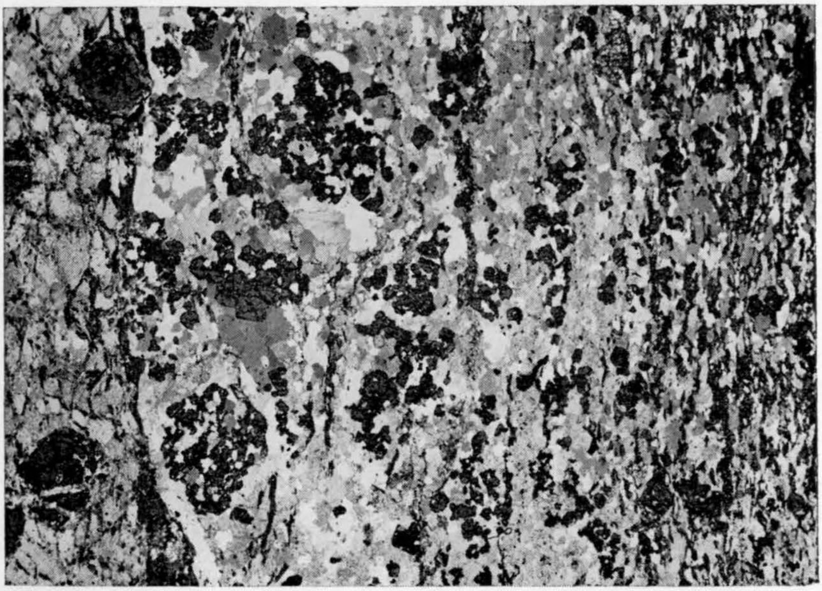

Fig. 2. Bands of andesine-garnet (far left) and quartz-clinozoisite-andesine (remainder). Note the white bands (sericite) in garnet, especially at the lower left. From the top of the Brasstown Formation at Marble Hill. Photomicrograph, partly crossed nicols, X8.

PLATE 3

and strewn along the foliation planes are also common (Pl. 3, fig. 1).

Cross-folding is the cause of these textural changes and has produced the most noteworthy results in the garnets of the Andrews Schist.

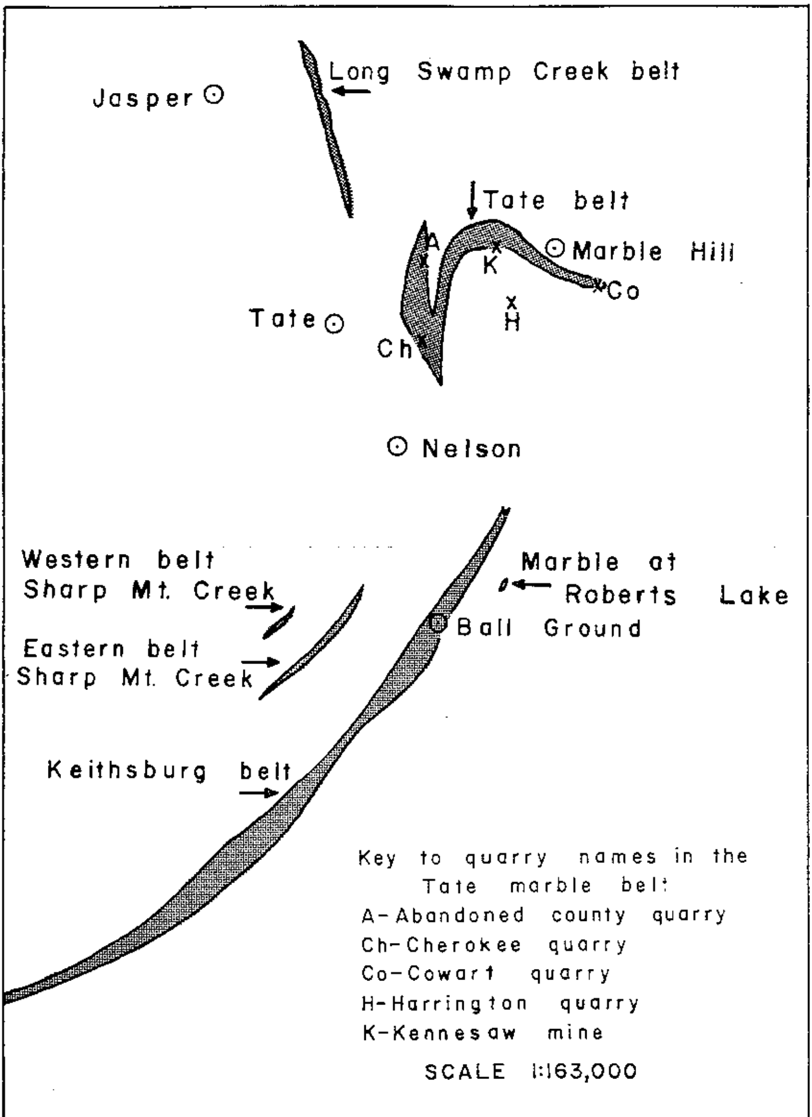

Fig. 4. Sketch map of the Tate quadrangle showing marble belts, quarries and important towns.

Contact relations with the overlying Murphy Marble. A gradational contact between the Brasstown Formation and the Murphy Marble can be observed at a few localities (Furcron and Teague, 1945, figure 5). Quartzose and micaceous layers are interbedded with marble over a distance of about five to ten feet on the east side of Long Swamp Creek in the valley east of Jasper, and on the hillside east of the Cherokee quarry (located on figure 4). No detailed information was available concerning the contact in the vicinity of Marble Hill until recent core drilling was completed. The petrography of two samples from the core is described below.

Biotite quartzite and a little muscovite schist with small garnets constitute the uppermost portion of the Brasstown Formation core. A thin section also showed abundant pyrite grains. Most of the core is probably like this sample.

Another thin section was cut from the Brasstown Formation core one and one half feet down from the top of the quartzite-schists. Bands of distinctly different composition are evident (Pl. 3, fig. 2). The band on the far left of the photomicrograph is composed mostly of feldspar and garnet. The feldspar has an extinction angle of 22° on poorly developed albite twins and a 2V of 90°. It is andesine, probably An_{38}. Most of the plagioclase in the sedimentary formations of the Tate quadrangle is oligoclase. The occurrence of andesine may be due to the presence of abundant lime in the rock. In other rocks near the top of the Brasstown Formation calcic-andesine and labradorite are present. The andesine in the drill core is clouded with sericite and other small alteration products. The garnets are rimmed with shreds of sericite and chlorite which also fill fractures in the garnet. A little sphene and ilmenite (?) occur. At the edge of this band on the far left of the photomicrograph is a concentration of chlorite. The next band to the right is essentially quartz, garnet, clinozoisite, and andesine, with a little chlorite. Just beyond the right edge of the photomicrograph of the drill core is another band of clear quartz and the beginning of a second andesine-garnet band.

The drill core is rich in calcite for a few inches below these calc-silicate lenses.

A thrust fault was mapped between the quartzite and marble by earlier workers at Marble Hill, but the calc-silicate and calcite lenses seen in the drill hole suggest a gradational contact between the Brasstown Formation and Murphy Marble.

The Murphy Marble

Name and correlation. Keith (1907) introduced the name Murphy Marble for marble separating the Valleytown and Andrews Formations near Murphy, North Carolina. He made the following statement (page 5): "The formation consists entirely of marble, rather fine grained and wholly recrystallized from its original condition. . ." He also said, "Its purity and freedom from argillaceous and sandy materials, such as make up the entire bulk of all the preceding formations, shows that the geographic conditions changed abruptly and entirely at that time." Later workers extended Keith's definition to include not only the pure marble, but also quartzose and micaceous marbles and even calc-schists which lie essentially on strike and at approximately the same stratigraphic level as the original Murphy Marble (Van Horn, 1948).

Pure calcite marbles, quartzose and micaceous marbles, and calc-schists all occur in the Tate quadrangle. Bayley (1928) included all these calcareous rocks in the Murphy Formation, but they may be separated into three groups, of which at least one does not properly belong in the Murphy Formation.

The first group consists of calcite marbles, with quartz and mica abundant only where the marble grades into the overlying and underlying formations. These relatively pure marbles occur between the Brasstown Formation and the Andrews Formation and they clearly fit Keith's original definition of the Murphy Marble as outlined above.

The second group consists of quartzose and micaceous marbles and calc-schists. These occur within the Andrews Schist, which lies above the Murphy Marble (table I). These marbles enclosed in the Andrews Schist are considered as a facies of that formation and are discussed with it.

The third group of marbles, called the Long Swamp Creek belt, and the Western belt on Sharp Mountain Creek (figure 4), are locally dolomitic, but generally lack siliceous minerals. These will be discussed with the Murphy Marble for reasons given on page 29, but aside from the fact that they are surrounded by outcrops of the Brasstown Formation, their exact stratigraphic position could not be determined.

Fig. 1. Coarse-grained calcite marble typical of the marbles found in the Tate belt and the Harrington quarry. The colorless grains at the top are phlogophite, and the colored ones of high relief are sphere. Photomicrograph, plain light, X10.

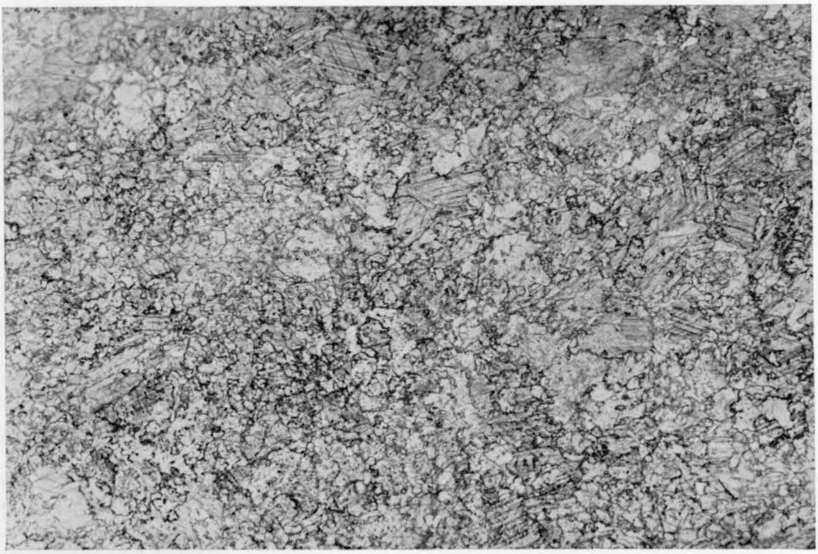

Fig. 2. Crushed marble from the intensely cross-folded portion of the syncline near Marble Hill. Photomicrograph, plain light, X7.

PLATE 4

TABLE 3

CHEMICAL ANALYSES OF MARBLE

	1	2	3	4	5	6	7
CaO	52.2	51.1	53.4	53.76	32.68	31.00	50.40
MgO	1.7	2.75	0.65	1.34	17.23	20.54	2.14
SiO_2	2.33	2.33	2.25	------	------	------	------
Al_2O_3	------	------	------	------	------	------	0.20
FeO	------	------	------	------	0.56	------	0.63
Fe_2O_3	0.029	0.029	0.29	0.15	0.25	0.79	1.00
MnO	0.04	0.02	0.02	------	0.07	------	------
CuO	4ppm	0.00	0.00	------	------	------	------
H_2O	0.40	0.45	0.40	0.02	0.30	0.02	0.20
CO_2	43.1	43.15	42.95	43.71	45.80	46.78	42.26
Ign	------	------	------	------	------	------	0.20
Total	99.799	99.829	99.96	98.98	96.89	99.13	97.03

Numbers 1 to 3 courtesy of the Georgia Marble Company (from Marble Hill, Georgia). Numbers 4-7 modified after Bayley, 1928, p. 80. (From Long Swamp Creek Belt).

Distribution. Marble belonging to the Murphy Formation occurs in the "Tate belt", at the Harrington quarry, and also near Roberts Lake (figure 4, and Plate I). The marbles mentioned in the third group above probably also belong to the Murphy Formation.

Tate belt. Pure, high-calcite marble makes up most of the belt (table 3). The marble is generally coarse, with the grain size averaging two to four millimeters (Pl. 4, fig. 1), but some marble in the east-west trending part of the belt is crushed to a fine-grained mosaic (Pl. 4, fig. 2). In all the marble, calcite twinning on $[01\bar{1}2]$ is common. Minor constituents include quartz, muscovite, phlogopite, apatite, sphene, graphite, zoisite, pyrite, tremolite and hornblende. Fuchsite has been identified from the Cherokee quarry (Hurst, personal communication).

An indistinct foliation is produced by mica flakes scattered in parallel planes and by blue-gray streaks made of impurities too small to be identified. The foliation generally parallels the bedding in the adjacent rocks but in places the foliation is folded or even thrown into small irregular swirls. The folds are overturned to the west where the marble trends north-south, and to the north where it trends east-west.

Fig. 1. Banded, graphitic marble at the Creole quarry. Note that the layer of white marble changes color rather abruptly along its strike.

Fig. 2. Small overturned folds in dolomitic marble. Scale can be taken from the one inch diameter pipe in the foreground.

PLATE 5

Small portions of this marble belt are distinctly different from the white marble mentioned above. Light to brilliant pink marble, with abundant lenses of hornblende schist and biotite schist occurs at the Etowah quarry, a few hundred feet northeast of the Cherokee quarry. A graphitic marble occurs at the Creole quarry a few hundred feet north of the Cherokee quarry. The graphite content is irregular and changes rapidly both across and along the strike (Pl. 5, fig. 1). A fine-grained dolomitic marble occurs at the abandoned county quarry (figure 4).

The marble ends in the valley north of the Cherokee quarry by a gradual facies change into schist. Drill holes and outcrops in the marble show progressively more and more quartz and mica in the marble to the north. It is also possible that the marble thins by lensing, but the only evidence for this is the rapid decrease in the width of the calcite-bearing rocks in the northern end of the valley.

The marble grades upward into calc-schists of sedimentary origin along much of the Tate belt (p. 30).

The contact relations with the underlying Brasstown Formation were discussed on p. 24.

Marble at the Harrington quarry. The Harrington quarry has been filled with water for many years, and only a few outcrops around the edges are available for study. However, the marble is known to be uniformly white and coarse-grained, like the marble in the Tate belt (Pl. 4, fig. 1). Thin quartz veins and pegmatites occur in the marble at the Harrington quarry. A calc-schist occurs between the marble and the overlying Andrews Schist, just as in the Tate belt.

Marble at Roberts Lake. The small outcrop of marble at Roberts Lake has been covered by the debris from a nearby mica prospect, but a little marble float is present. Bayley (1928, p. 94) saw outcrops and drill cores from this marble and he described them in detail. Apparently, from his description, a thin calc-schist also lies between this marble and the Andrews Schist.

Long Swamp Creek marble belt. A belt of dolomitic marble, three miles long and up to 500 feet wide occurs east of Jasper. Small scale folding (Pl. 5, fig. 2) and the fact that the top of the marble is not exposed, make it impossible to determine the original thickness of the beds. The marble is quite uniformly fine-grained, and is white to slightly bluish white. Silicates are generally absent and the dolomite content is high, as indicated in the chemical analyses of table 3. Impurities include quartz, muscovite, phlogopite and amphiboles. Bedding, although indistinct, can be seen to parallel the bedding of the adjacent micaceous quartzites.

The Long Swamp Creek marble belt is provisionally included in the Murphy Marble for two reasons. First, the marble consists of carbonates and a few silicates, as it should to fit Keith's original definition. Also, the marble may lie in the axis of a syncline of the Brasstown Formation which would put the marble above the Brasstown Formation at the defined stratigraphic position of the Murphy Marble.

Two instances of poorly developed graded bedding suggest that the Long Swamp Creek marble belt does lie in the trough of a minor syncline at the top of the Brasstown Formation. Scattered pebbles in quartzites on the hillside west of Long Swamp Creek are graded from coarse at the bottom of the bed to fine at the top, suggesting that these beds are right side up. Indistinct grading from fine to coarse of sand-size particles in quartzites east of the marble suggests the possibility that the quartzites are overturned.

Barring any question on the validity of the grading itself, repetition of beds by close folding may make it impossible to use scattered examples of graded bedding to determine the top and bottom of a thick sequence of rocks. The top of the beds in one exposure does not necessarily indicate the top of the entire stratigraphic section.

Western belt of marble on Sharp Mountain Creek. This belt is known only from a few small exposures of fine-grained white dolomitic marble. These exposures and the marble in the Long Swamp Creek marble belt both lie at approximately the same distance from the Nantahala Formation along the curving arc of the syncline. The exact stratigraphic position of neither marble could be determined.

The Marble Hill Hornblende Schist

Name and correlation. Calc-schists and biotite-hornblende schists lie between the Murphy Marble and the garnet-mica schists of the Andrews Formation. Bayley, with reservations, included these schists in the Roan Gneiss saying (1928, p. 109)

"At most places the relations of these rocks to the marble have not been determined, and because of their similarity with the Roan gneiss they are mapped as pre-Cambrian." The present work shows that these schists have a distinctive though somewhat variable mineralogy; they occur at a well defined stratigraphic horizon; and they consitute a mappable unit. The hornblende schists, then, clearly require a formational name, and the designation **Marble Hill Hornblende Schist** is suggested by the excellent exposures of the schist near the town of Marble Hill.

Distribution and thickness. The Marble Hill Hornblende Schist occurs discontinuously along a curving belt about 4½ miles long. The first outcrops appear ¼ mile south of the Cherokee quarry (quarries and other place names are located on figure 4). At the end of the valley one mile south of the quarry, the schist turns northward and parallels the marble in its curving trend northward and eastward to Marble Hill; there it turns southeastward for about ¾ mile to the Cowart quarry where it thins and disappears. The maximum thickness along this belt is 300 feet (Plate I). The Marble Hill Hornblende Schist reappears farther south at the Harrington quarry and Bayley (1928, p. 94) reported another hornblende schist 4½ miles farther south near the marble at Roberts Lake. The exposure is now covered, but his description suggests the presence of the Marble Hill Hornblende Schist at this locality. At both localities the hornblende schist lies at the same stratigraphic position beneath the Andrews Schist and above the Murphy Marble.

Contact relationships. Calc-schists at the base of the formation grade downward into calcite marble through a zone about five feet thick. The boundary between the formations is drawn where the percentage of dark colored minerals exceeds that of calcite.

The upper contact of the formation is covered and was not observed in the field, but can be located within 25 feet at many localities.

Megascopic description. The calc-schist consists essentially of well foliated calcite and hornblende. Calcite folia alternate with hornblende to produce a good schistosity. Oriented biotite accentuates the schistosity in many places. In addition, the rock shows a coarser layering of calcite-rich and hornblende-rich bands, each of which is in itself thinly foliated. These layers

TABLE 4

MODAL ANALYSES OF ROCKS FROM THE MURPHY, MARBLE HILL & ANDREWS FORMATIONS & A URALITIC GABBRO

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Quartz	1	1	Tr	2	24	11	70	32	37	26	9	13	15	15	Tr	
Oligoclase	3	10	2	6	16	4	5	2								
Labradorite											1	23		7		
Bytownite															18	5
Biotite	20	1	15		10	5	9	5	9	5					1	1
Muscovite							8	37	40	36	20	6	9	17		
Garnet							Tr	21	11	14						
Hornblende	46	54	47	80	39	16									22	50
Chlorite						1	Tr				4	Tr	Tr	3		
Sphene	4	4	3	6	4	Tr		1	1	Tr	Tr		Tr		7	5
Epidote				Tr											6	
Zoisite											19	Tr	Tr	5		
Clinozoisite						2										8
Staurolite								2	1	19						
Kyanite										Tr						
Calcite	27	30	32	5	2	59	6				39	35	76	45	Tr	1
Opaque		Tr			5	3	1	1	1	Tr	Tr	1		1	Tr	3
Phlogopite											8	21	Tr	8		
Pyroxene															45	28

Modal analyses in volume percentage rounded off to nearest percent

1. Marble Hill calc-schist.
2. Marble Hill calc-schist.
3. Marble Hill calc-schist.
4. Marble Hill Hornblende schist.
   Numbers one to four are from the side of the valley half a mile east of the Cherokee quarry. Number one is stratigraphically lowest and number four highest in the formation.
5. Calc-schist contained in the upper part of the Murphy Marble or the lower part of the Marble Hill Schist. From the top of the workings at the Kennesaw mine.
6. Amphibolitic marble from the valley one and a half miles north of the Cherokee quarry.
7. Andrews micaceous quartzite, quartz rich phase, two miles north of the Cherokee quarry.
8. Andrews Schist, half a mile southwest of the Kennesaw mine.
9. Andrews Schist, half a mile west of the Cherokee quarry.
10. Andrews Schist, half a mile east of the Cherokee quarry.
11. Andrews calc-schist on Hickory Log Creek, one mile southwest of Chalcedonia Church.
12. Andrews calc-schist at the eastern edge of the Keithsburg Belt two miles northeast of Ball Ground.
13. Andrews Micaceous marble from the small outcrop on Sharp Mountain Creek one and one-quarter miles northwest of Sharp Mountain Church.
14. Andrews Calc-schist, isolated outcrop southeast of the calcareous schists called the Eastern Belt on Sharp Mountain Creek, one mile northwest of Ball Ground.
15. Uralitic gabbro from the large elliptical mass east of Marble Hill.
16. Same location as 15.

are a few millimeters to a centimeter or two thick, and generally can be followed for only a few feet along an outcrop before they pinch out or merge with adjacent layers. Exposures near the Kennesaw mine and Marble Hill show large ellipsoidal voids in the schist. The longest axis of a void is commonly about 30-40 centimeters and the shortest about 5-10 centimeters. Presumably they were formed by the solution of calcite lenses.

At the top of the formation the hornblende content increases (table 4) and the schistosity is not pronounced.

Microscopic description and origin of the texture. Variable amounts of a yellow green hornblende (2V-72°) with one-quarter millimeter eudhedral cross sections are prominent in thin sections (plate 6, figs. 1 and 2). Calcite twinned on [$01\bar{1}2$] occurs in flat grains and clusters parallel to the foliation. Biotite, about one-half a millimeter long, wraps around the hornblende and the calcite. The biotite is commonly greenish yellow to olive brown or moderate brown. A little quartz is present. Small oligoclase grains are equant, but larger ones are elongated parallel to the foliation. Dull gray to yellow green epidote is roughly circular and lacks distinct crystal outlines (Pl. 6, fig. 2). The epidote lacks inclusions, does not warp the foliation very much considering its large size, and has many serrations or indentations along its margins. Rolling of an early formed porphyroblast might account for the features seen in the epidote crystals. However, these porphyroblasts were observed in only one thin section, and their origin is not entirely clear. Garnet porphyroblasts in the Andrews Schist to the east are crushed and smeared through the rocks (Pl. 8, fig. 2), and garnets of the Canton Schist show rolling without crushing (Pl. 11, fig. 2).

Sedimentary origin of the schist. The gradational contact of the Murphy Marble and the Marble Hill Hornblende Schist, and the presence of abundant layers and small lenses of calcite through all but the top beds of the Marble Hill Hornblende Schist indicates that the schist is of sedimentary origin. The schist resembles other calc-schists of known sedimentary origin within the area. The calc-schist at the Kennesaw mine (modal analysis number 5 of table 4) has 24 percent quartz in it and clearly was derived from a sediment rather than from a basic igneous rock. The amphibolitic marble shown as mode 6 in table 4 contains rounded quartz grains. The quartz appears to be

Fig. 1. Calcite-biotite-hornblende schist. Marble Hill Schist from the side of the valley due east of the Cherokee quarry. Photomicrograph, plain light, X24.

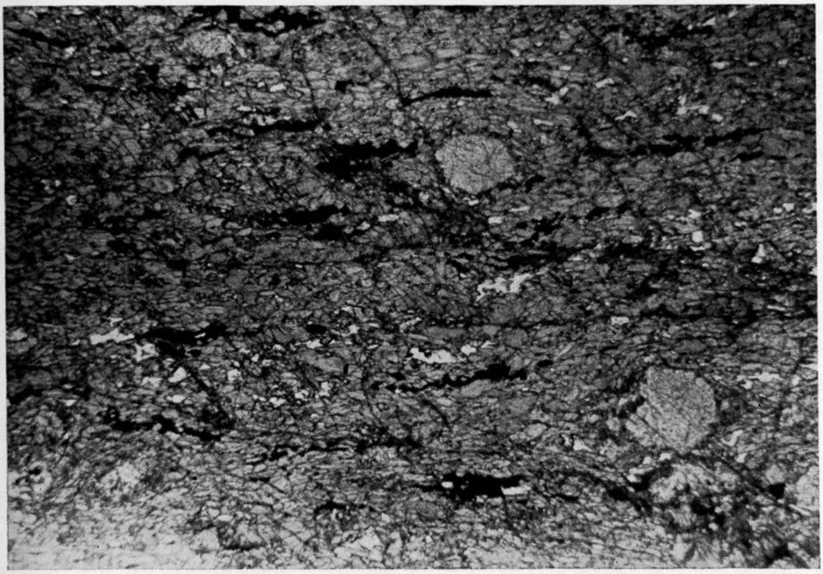

Fig. 2. Epidote porphyroblasts in a matrix of hornblende with pyrite and (colorless) oligoclase. The fractures are locally developed, closely spaced joints. Marble Hill Schist, due east of the Cherokee quarry. Photomicrograph, plain light, X8.

PLATE 6

detrital and apparently survived metamorphism by "floating" in a matrix of calcite.

In an attempt to obtain additional evidence of the origin of the schist, the chemical composition of the schist was determined by calculations from modal analyses and compared with igneous and sedimentary rocks. The modes were calculated once using a very aluminous hornblende, and once using a more "normal" hornblende. Also, the author calculated the compositions using the calcite content as shown in the modes (table 4) and then on a calcite-free basis to compare the non-calcite residue with igneous and sedimentary materials. These results were inconclusive because various limestones, marls, and basic igneous rocks have been described which approximate the compositions computed from the modes (Muir and Hardie, 1956).

The original sedimentary material could have consisted of dolomite, calcite, clay minerals low in potash, and a little quartz. Also, the abundant hornblende requires the original sedimentary material to have been rich in magnesia and to have an appreciable iron content. The exact composition of the hornblende is not known, but whatever magnesia and iron it contains could easily be supplied from a sedimentary source. Magnesia is abundant in the underlying marble which is locally dolomitic. Iron was abundant enough in the lowest beds of the overlying Andrews Schist to produce staurolite porphyroblasts two to three inches in length which locally constitute nearly a quarter of the schist. In fact, an abundance of iron in the beds just above the Murphy Marble is typical of the rocks all along the Murphy Syncline. Limonite from the base of the Andrews Schist was mined in the Mineral Bluff quadrangle (Hurst, 1955, p. 123), and Keith (1907, p. 5) found abundant brown hematite in the Andrews Formation of the Nantahala quadrangle.

The Andrews Schist

Name and correlation. Keith (1907) introduced the name Andrews Schist for ottrelite schists which lie between the Murphy Marble and the Nottely Quartzite in the Nantahala quadrangle. Hurst (1955) applied the name Andrews Schist to rocks having the same stratigraphic limits as Keith specified, although LaForge and Phalen (1913) had assigned the rocks to other formations. A thin calc-schist, the Marble Hill Formation, overlies the Murphy Marble in the Tate quadrangle. The schists above the Marble Hill Formation cannot be traced into the Andrews Formation of the Mineral Bluff quadrangle, but they are considered correlative on the basis of similar lithology and by their occurrence at approximately the same stratigraphic level.

Megascopic description. The Andrews Formation contains much garnet-mica schist which in places has either staurolite or kyanite or both. Coarse-grained muscovite is the dominant mica, but a little biotite is present. Dodecahedral garnets 2 to 3 millimeters in diameter warp the foliation. Mica and garnet appear to be the only constituents of the schist when foliation planes are viewed, but abundant lenses of quartz are obvious in sections cut across the foliation. Graphite colors the schist black in one area. Feldspathic quartzite beds a few inches to a few feet thick occur in the schist. The variable mineralogy of these rocks can be seen from the modes 7-10 to table 4.

Calcareous facies occur in the schists, and consist of fine- to medium-grained, blue-gray, micaceous marbles and calc-schists. Phlogophite and muscovite produce a strong foliation. Mica-rich layers alternate with layers of calcite and mica or with layers of pure calcite. The calcite-mica layers grade laterally into mica schist, but the layers of pure calcite are in distinct lenses which pinch out without noticeable gradation with the adjacent schist (Pl. 7, Figs. 1 and 2).

Distribution. The Andrews Formation occupies several belts in the central part of the quadrangle (Plate I). The repetition of the formation is due to folding, and the distribution of the resulting anticlines and synclines is shown in the cross section of figure 5.

The calcareous portions of the formation were considered by Bayley as part of the Murphy Marble and he indicated their

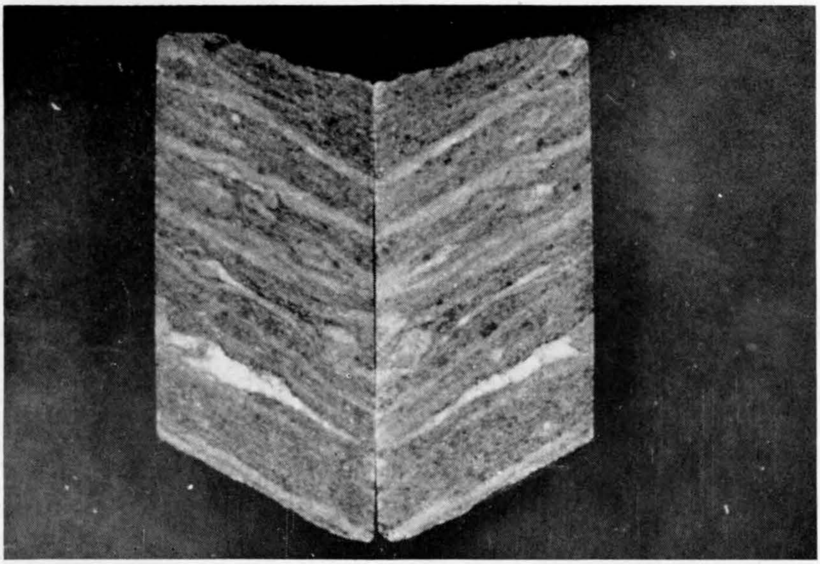

Fig. 1. Calcite-rich layers in the Andrews Schist. Drill core from one and one-half miles northwest of the Cherokee quarry.

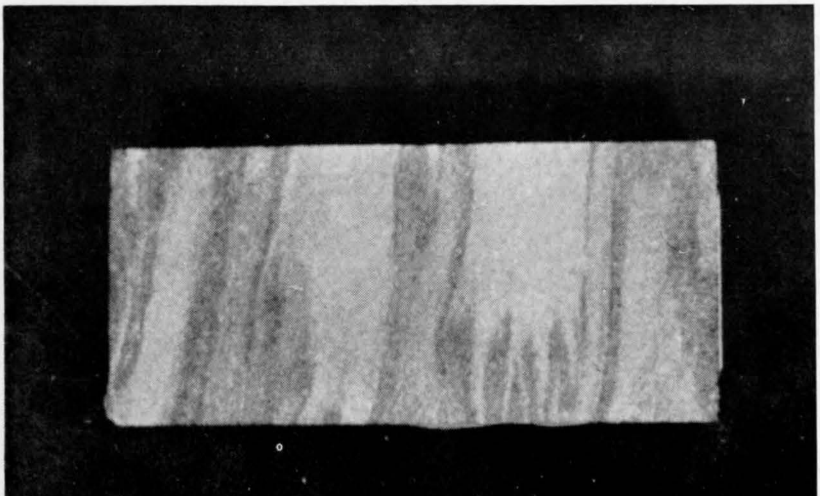

Fig. 2. Thin micaceous beds feathering-out into calcite layers. Same location as Pl. 7, Fig. 1.

PLATE 7

distribution by giving them names based on the localities where they occur. These calcareous schists and micaceous marbles are designated on figure 4 as the Keithsburg belt and the Eastern belt on Sharp Mountain Creek. Bayley gave a description of the distribution of the marble in the Keithsburg belt. At a locality two miles northeast of Ball Ground Bayley drew a thrust fault at the marble-schist contact in the lowland just west of Long Swamp Creek. Remapping of this locality shows that the marble actually continues to the base of a small hill about 500 feet to the east of Bayley's boundary. This location is important because it shows a quartz-rich marble grading through calc-schists to garnet-mica schist. This gradational contact is a strong argument against the Whitestone thrust which Bayley drew along the Keithsburg belt.

The graphitic schists within the Andrews Formation were thought by Bayley to belong to the Nantahala Formation. Their distribution can be seen on figure 3 where they occupy the area between the two thrust faults mapped by Bayley on the east side of the Keithsburg belt.

Microscopic description of the calcareous portions of the formation. The same minerals occur in all the calc-schists but with highly variable proportions (table 4, modes 11-14). Calcite occurs as elongated grains in schistose lenses, but it is more equidimensional in lenses of nearly pure calcite. Likewise, quartz is generally equidimensional. Muscovite and phlogopite impart a good foliation to the rocks. Zoisite is bladed and accentuates the foliation. Porphyroblasts of labradorite appear to have formed late, for they contain abundant inclusions of calcite and a little mica. The porphyroblasts warp the foliation planes where mica is abundant. Where calcite is abundant the porphyroblasts grow around and enclose the grains rather than warping the foliation. Only in calcite-rich rock are these calcic plagioclases found. The usual plagioclase in the syncline is oligoclase.

Microscopic description of the garnet-mica schists. Flaser texture is common to all the schists in the formation except in the area east of Tate. The schists near the Cherokee quarry (Pl. 8, Fig. 1) are typical; they contain lenses of sutured quartz five to twenty millimeters long lying between thick wisps of muscovite and a little biotite. Subhedral staurolites two to five millimeters long are common. Garnets are subhedral to euhedral, two to three millimeters in diameter, and have a row of minute quartz inclusions parallel to the boundaries of the grains.

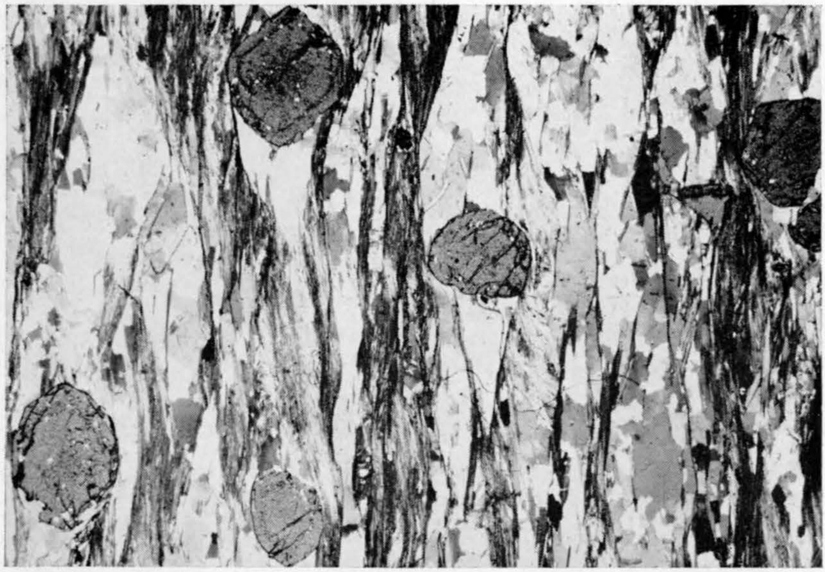

Fig. 1. Andrews quartz-mica schist along railroad one-half a mile northwest of the Cherokee quarry. Note the outline of the inclusions within the garnets. Photomicrograph, partly crossed nicols, X8.

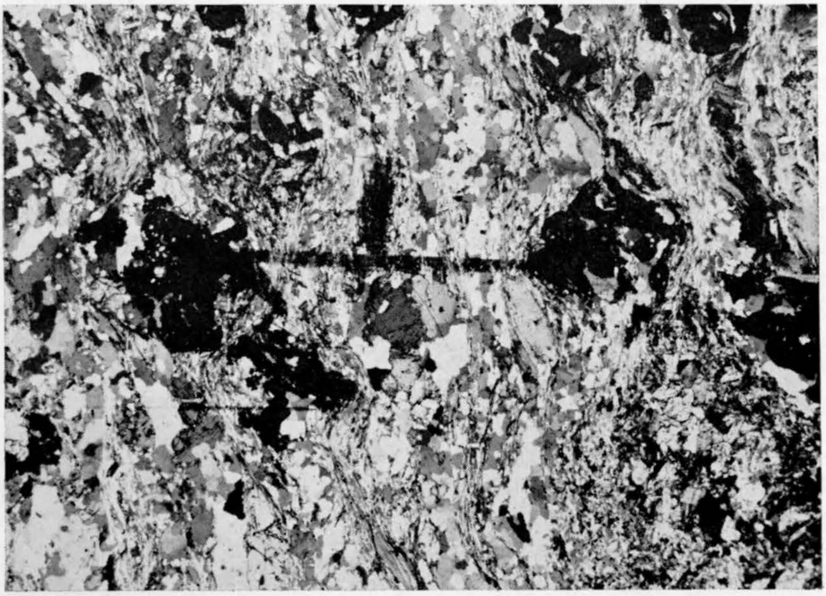

Fig. 2. Crushed garnets in the Andrews Schist between the Harrington quarry and Marble Hill. The tic-mark on the orientation arrow points up the foliation which dips gently to the southeast. Photomicrograph, partly crossed nicols, X8.

PLATE 8

The texture is slightly different in the schists on the hillside half a mile due east of the Cherokee quarry. There the garnets are not as euhedral as those on the west side of the marble and some show rings which are broken and partly torn from the cores.

Figure 2 (Plate 8) from the schist in the valley between the Harrington quarry and Marble Hill, shows a more advanced stage. The garnets have been broken up and strewn through the rock; crystal faces have been broken away along the rows of inclusions and some of the garnets are left as nearly circular grains. Muscovite, which in rocks to the west is in large, broad wisps, is in small plates and shreds between clusters of quartz grains whose boundaries are sutured. Small kyanite needles and blades lie in the cleavage and along the edges of the muscovite. A similar contrast in textures in the western and eastern exposures of the Brasstown Formation and the Murphy Marble can be seen in figures 1 and 2 (Pl. 2) and in 1 and 2 (Pl. 4).

Cross-folding (page 60) is responsible for both these textural changes, and for the abrupt divergence in trend of outcrop patterns in all the formations east of Tate.

METAGABBRO

A uralitized gabbro crops out east of Marble Hill in an oval-shaped mass and as sills in the adjacent quartzite (Plate I). The gabbroic texture is preserved in patches a few millimeters across enclosed in a sparse matrix of hornblende which has developed from pyroxene (Pl. 9, Fig. 1). The mineralogic composition of the gabbro is shown in table 4 (Mode 15 and 16). The average metagabbro is nearer that of modal analysis number 15 than number 16 (Table 4).

The relict patches of gabbro consist of equant augite and bytownite grains 3-5 millimeters in diameter. Green uralitic hornblende partly replaces the pyroxene. Thin (1/64-1/32 mm.) reaction rims of clinozoisite separate bytownite from augite. Sphene occurs as distinct grains, with scattered ilmenite inclusions, and as rims on ilmenite, suggesting that sphene replaces ilmenite. Shreds of muscovite in small patches partially replace bytownite.

In contrast to the adjacent schists the uralitic gabbro is massive with none of the constituents showing any preferred orientation. There is no direct evidence to indicate when the gabbro was intruded, but its lack of a regional foliation even in thin sills indicates that it formed later than the major deformation which produced the surrounding schists and quartzites. The elongation of the gabbro parallel to the axis of cross-folding suggests that the gabbro was intruded along a fold axis. That the gabbro might have been intruded during the late stages of this cross-folding is suggested by the fact that one specimen shows a weak schistosity due to the parallel alignment of small lenses of partially altered gabbro in a matrix of oriented hornblende, but the general lack of foliation in all other specimens makes this inconclusive.

Fig. 1. Hornblende replacing augite in uralitic gabbro. Gabbro mass one mile east of Marble Hill. Photomicrograph, partly crossed nicols, X40.

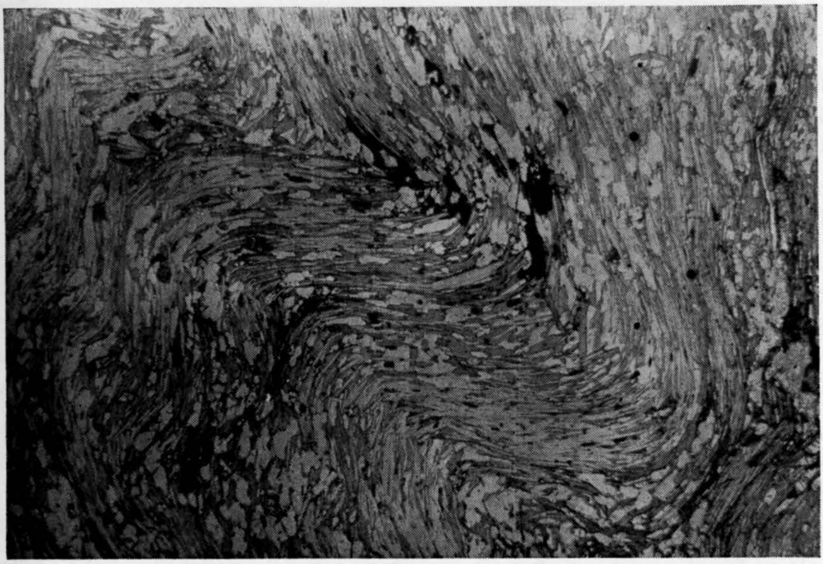

Fig. 2. Crenulations (L2) showing as small folds. Note the incipient fracture cleavage along the axial planes of the folds. Photomicrograph, nicols partly crossed, X25.

PLATE 9

PEGMATITES AND QUARTZ VEINS

The pegmatites of the Tate quadrangle have not been studied extensively in the course of this work, but earlier workers investigated them for their content of economically important minerals, especially muscovite (Galpin, 1915; Furcron and Teague, 1943; Heinrich, Klepper and Jahns, 1953.) Structural relations with the adjacent rocks are obscure due to poor exposures, but the pegmatites generally follow the foliation of the host rocks and cross-cutting was rarely observed. In the Marble Hill district cross-folds are common and both the pegmatites and the cross-folds are oriented northwest-southeast. Commonly the pegmatites are three to four feet wide and a few tens of feet long. Plagioclase, perthite, quartz and muscovite are the major minerals (Heinrich, Klepper, and Jahns, p. 378). Some quartz and perthite occur in graphitic intergrowths, and tourmaline, apatite and beryl occur in minor quantities.

The pegmatites within the zone of cross-folding do not appear to have undergone the marked granulation, shearing and partial recrystallization which has affected the host rocks. The pegmatites show a vague streakiness and a crude jointing, but "books" of muscovite up to three inches in diameter are oriented in many directions and the texture is relatively massive. Thus it appears that the pegmatites formed after the major deformation of the host rocks, perhaps in the late stages of the deformation that caused the cross-folding. Pegmatites were formed during the latest deformation at Ducktown, Tennessee (Hurst, 1955, p. 93) and Old Fort, North Carolina (Hamilton, 1957, p. 572).

Quartz veins. Quartz veins occur in all sizes from minute concordant stringers to large veins. Both long tabular and short ellipsoidal masses are common. Small quantities of muscovite and tourmaline occur in most veins.

METAMORPHOSED CALCAREOUS CONCRETIONS AND BEDS

The rocks now to be discussed have been known as "pseudodiorite" in the southeastern states. Keith (1913) coined the term for some igneous-looking rocks which he believed formed by "mineral recrystallization by solutions under pressure". That the rocks originated by the metamorphism of calcareous concretions and beds is now generally agreed. The term "pseudodiorite" should be abandoned as it has no true genetic connotation and it is only very vaguely descriptive.

Megascopic description.—The rocks are light gray to black and consist of medium to coarse-grained calc-silicate minerals. The rocks occur both as nodules and as beds. The nodules average four to six inches long and have the approximate shape of triaxial ellipsoids. The long and intermediate axes lie in the plane of the foliation, but there is little or no visible preferred orientation of the minerals within the nodules. The nodules are more resistant to weathering than their matrix and stand out in relief on the outcrops or occur as residual cobbles in the soil. They resemble in their physical and mineralogical aspects the nodules described by Pettijohn (1940) from the Archean of Ontario.

The calc-silicate minerals also occur in beds. The thickness of any bed probably does not exceed two or three feet. A banding due to layers of different mineral composition is prominent and is parallel to the foliation (which parallels bedding) of the adjacent metasediments. These bedded rocks strongly resemble the "bedded pseudodiorites" described by Hurst (1955, p. 28) from northern Georgia.

Distribution.—The nodules and beds occur in the Great Smoky, Nantahala, Brasstown, and Andrews Formations of the Tate quadrangle; along the Murphy Syncline in the Mineral Bluff quadrangle (Hurst, 1955); and in the nearby Ducktown Basin (Emmons and Laney, 1926). Occurrences outside the southern Appalachians are common, and have been discussed by Pettijohn (1940).

These calc-silicate rocks are more common in northernmost Georgia and southern Tennessee than in the Tate district, and have received much attention from the workers in these regions.

In the Tate quadrangle the beds and nodules are most common near the marble.

Microscopic description.—The nodules and beds are similar in texture and mineralogy, although the proportions of the minerals vary. Quartz is abundant (table 5) and occurs in granoblastic to slightly sutured grains which average about ¼ to ½ millimeter in diameter. A few grains are about one millimeter in diameter and show moderate to strong undulatory extinction. The small grains show no signs of strain and may be the broken fragments of the larger grains.

Clinozoisite and zoisite occur as discrete, randomly oriented columnar grains or as shapeless to round clusters of grains. The clinozoisite has a 2V of 72°, and the zoisite has a 2V of 30°.

An optically positive amphibole, probably hastingsite, is abundant. One grain showed a 2V of 76° and another a 2V of 78°. The angle between gamma and "c" in the first grain is 7° and 14° in the second. The hastingsite is spongy to crudely skeletal and occurs in grains about one-half a centimeter long which grow around and enclose other minerals.

Plagioclase occurs in grains ½ to 1 millimeter in diameter which enclose a few tiny round quartz grains. The plagioclase has a 2V of approximately 80° and the extinction angle on faint albite (?) twins is 34°. The plagioclase is probably calcic labradorite or perhaps bytownite.

Origin.—The association of lime silicates with quartz, their occurrence in metamorphosed arenaceous rocks and the nodular and bedded structures of the bodies are evidence that they are metamorphosed calcareous concretions and beds. (Emmons and Laney, 1926; Eskola, 1932; Runner and Hamilton, 1934; Pettijohn, 1940; Hurst, 1955).

TABLE 5

MODAL ANALYSES OF CALCAREOUS CONCRETIONS AND BEDS FROM THE TATE AND MINERAL BLUFF QUADRANGLES

	1	2	3	4
Quartz	25.7	40.2	41.36	21.26
Bytownite	0.0	0.0	31.79	22.91
Labradorite	2.8	0.0	0.00	0.00
Zoisite*	28.2	35.9	0.00	0.00
Clinozoisite*	8.6	0.0	4.00	39.53
Hastingsite	28.0	5.0	0.00	0.00
Hornblende	0.0	0.0	12.07	12.44
Garnet	3.6	8.0	4.00	1.97
Sphene	0.5	1.2	2.43	1.89
Opaque	2.1	0.8	1.71	0.00
Calcite	0.0	6.9	1.57	0.00
Apatite	0.0	0.0	0.57	0.00
Colorless mica	0.0	0.0	0.29	0.00
Chlorite	0.0	0.0	0.21	0.00
Unidentified non-opaques	0.4	1.8	0.00	0.00
Total	99.9	99.8	100.00	100.00

*Zoisite and clinozoisite are not always distinguishable on the flat stage, and some of one may be included with the other.

1. Calc-silicate bed in the Andrews Schist, northern tip of Keithsburg marble belt.
2. Calc-silicate bed in the Great Smoky Formation, Dawson County, just east of the Tate quadrangle.

3 and 4. Pseudodiorites from the Mineral Bluff quadrangle, Hurst, 1955, p. 29.

The general similarity of these rocks with the calc-schists and siliceous marbles of the Andrews Schist can be seen by comparing the modes of tables 5 and 4. With an increase in the calcite content and a decrease in quartz, the hard, resistant, concretions and beds grade into soft, easily weathered calc-schists and micaceous marble.

STRUCTURES

Introduction.—The megascopic structures of the Murphy Syncline in the Tate quadrangle will be discussed first, and then the petrofabrics. Structural and stratigraphic data will then be synthesized to explain the outcrop pattern.

Bedding

Bedding can be seen as interlayering of quartzose and micaceous units up to many tens of feet thick. Gradations between rock types along the bedding are important in interpreting the structures. Small scale gradations, or facies changes, can be seen in plate 5 fig. 1 and in plate 7 figures 1 and 2. Larger changes cannot be observed but must be assumed to explain the outcrop pattern of the schist and marble between Tate and Marble Hill.

Graded bedding.—Relict graded beds can be recognized in the metasediments of the Murphy Syncline in the Tate quadrangle, but they are not as common or as well developed as they are in less metamorphosed rocks farther to the north and west. The graded beds consist of small pebbles and granules of both quartz and feldspar dispersed in a fine-grained matrix. The pebbles decrease both in size and in number from the bottom to the top of each bed. The beds generally are not more than a foot thick.

Grading has been reversed by metamorphism at a few localities. The coarse-grained quartzose base has undergone little size change during metamorphism, while the originally fine-grained argillaceous upper part has recrystallized into coarse mica.

Schistosity

The term schistosity is used here as "That variety of foliation that occurs in the coarser-grained metamorphic rocks. Generally the result of the parallel arrangement of platy and ellipsoidal mineral grains". (AGI, Glossary of Geology and Related Sciences, 1957).

Schistosity (S2) is parallel to bedding, even on the crests of folds. It is due to the orientation of cleavage plates (001) in mica parallel to bedding (S1), and to a lesser extent to flattened grains of quartz and feldspar. In marble, the schistosity is produced by flattened calcite grains and to a slight extent by the parallelism of calcite twin lamellae. Fabric studies show that the bedding-schistosity surface is the only S-plane developed which has a mineral orientation except where cross-folding occurs.

Fracture Cleavage

The term fracture cleavage is used here to mean a system of fractures, similar to joints but generally more closely spaced which are not determined by any prominent mineral orientation. The fracture cleavage (S3) obscures the bedding, but a regional pattern could not be determined because it occurs at only a few localities. The S3 is probably parallel to the axial planes of small folds which lie across the trend of the major folds, and the intersection of S3 and S1 produces a lineation parallel to the trend of the small fold axes. An incipient fracture cleavage along the axial planes of small folds can be seen in plate 9, figure 2.

Lineation

Introduction.—Lineation is used here to describe any linear structure without regard to its origin (Cloos, 1946, p. 1). The lineations, especially fold axes, crenulations, and the girdle axes of fabric diagrams, are the most diagnostic structural elements available for outlining the complex folding in the Tate and adjacent quadrangles.

Folds and fold axes.—The major fold within the Tate quadrangle is the Murphy Syncline shown on Plate I and in the cross-section of figure 5. The outlines of the syncline in Georgia and the relationship of the syncline to other linear structures in and adjacent to the Tate area is shown in figures 2 and 6. A few small folds at the scale of an outcrop or hand specimen parallel the arc-shaped trend of the syncline. Most small folds, however, lie across the trend of the synclinal axis. These folds grade downward in size into crenulations, some so small they are barely visible.

The next fold to the west of the Murphy Syncline is a large, open fold, the Salem Church Anticline. The anticline plunges to the northeast in the northwestern part of the Tate quadrangle (figures 2 and 6). The northwestern limb of the anticline was traced through the Waleska quadrangle where it is the eastern limb of a syncline mapped by Smith (1959).

Crenulations.—The crenulations consist of little ridges of mica about ten millimeters long and one to two millimeters high on the planes of schistosity. Figure 2 (Plate 9) illustrates very large

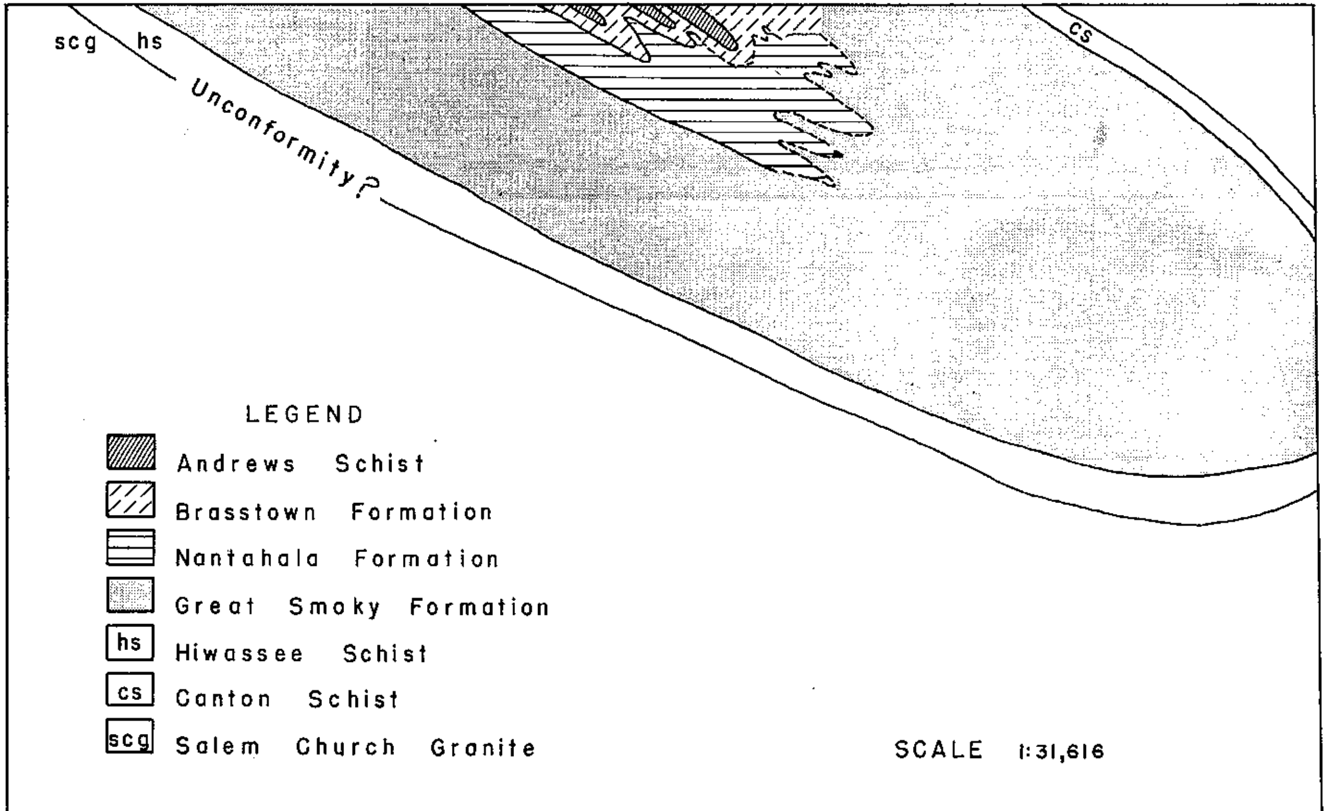

Fig. 5. Generalized cross-section of the Murphy Syncline along a northwest - southeast line one mile north of Ball Ground. Thin calcareous portions of the Andrews Schist are not shown.

crenulations in a thin section. The crenulations are the most frequently observed type of lineation in the area, and their distribution is shown on figure 6.

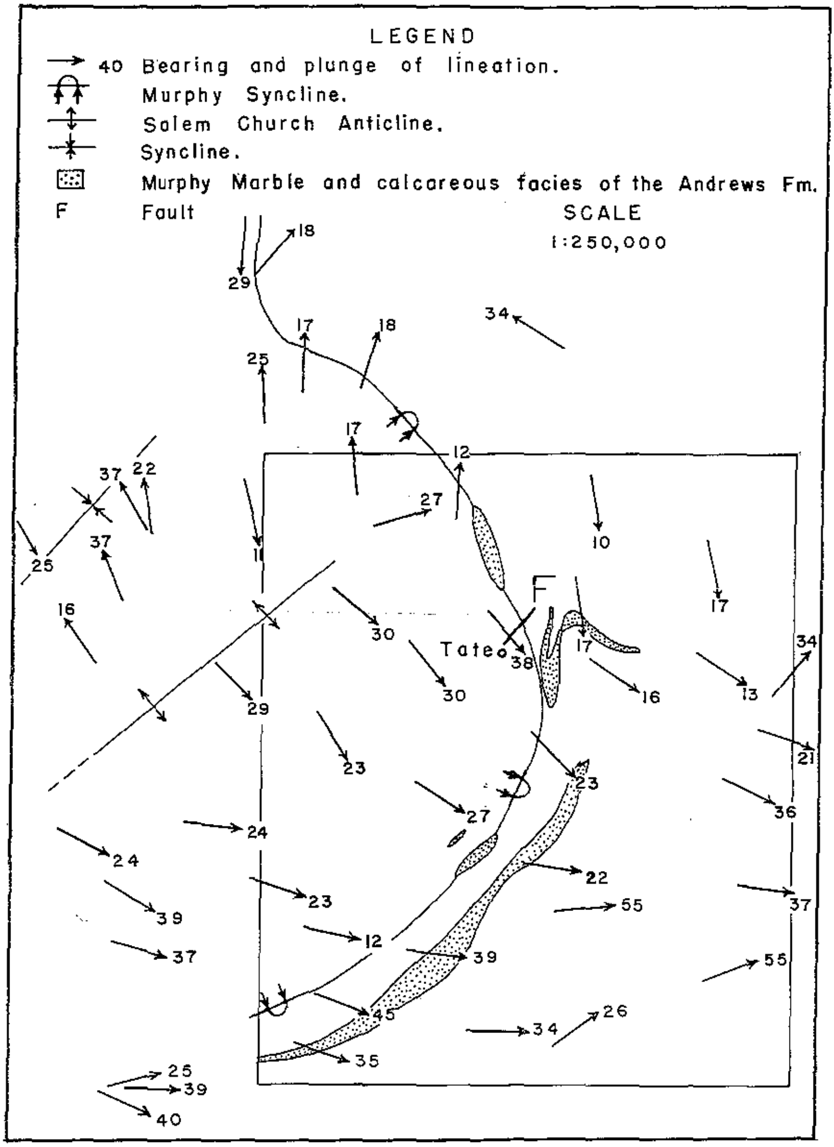

Fig. 6. Sketch map to show the major folds and crenulations (L2) in the Tate and adjacent quadrangles. The map generalizes the orientations measured at 350 localities.

Other lineations.—The longest axes of elongated pebbles, hornblende crystals, ellipsoidal quartz lenses, and the intersection of S1 and S3 outline lineation at a few places. Lineation due to girdle axes in the fabric of quartz, mica and calcite is discussed later.

Classification of lineations.—The Murphy Syncline has an arc-shaped trend through the Tate quadrangle (Plate I). All the lineations which parallel this trend are designated L1. The crenulations and some of the small folds plunge gently to the southeast and wrinkle the planes of schistosity. These lineations are designated L2. By definition, a set of fold axes lying across a second set of fold axes constitutes "cross-folds" (Van Hise, 1894, and Bhattacharji, 1958). Where the phrase, "the cross-folds", is used in the following discussions, the L2 direction is indicated. Almost all the girdle axes found in the petrofabric studies can be unequivocally assigned to L1 or to L2 (pages 54 to 59). Most of the Salem Church Anticline lies in the Waleska quadrangle, and more work is required before it can be related to the folds in the Tate quadrangle.

Faults

Only a few faults were observed, probably because they are obscured by weathering. Faults striking north-south can be seen in the Brasstown Formation just north of Marble Hill. The rocks on both sides of the faults are quartz schists, and so the displacement cannot be measured.

No faults could be traced, but one could be projected along its strike from one outcrop to another, and this fault is shown on figure 6.

Joints

Joints are found at right angles to the curving trend of the syncline throughout the quadrangle (figure 7). In addition, joints are found at right angles to the east-west trend of the marble belt east of Tate. There is nothing diagnostic about these joints to favor one hypothesis of origin over another, although extension perpendicular to the plane of the joints in marble is indicated by the growth of calcite in the joints. Calcite grains grow perpendicular to the surface of the joints and make veinlets one to two millimeters wide.

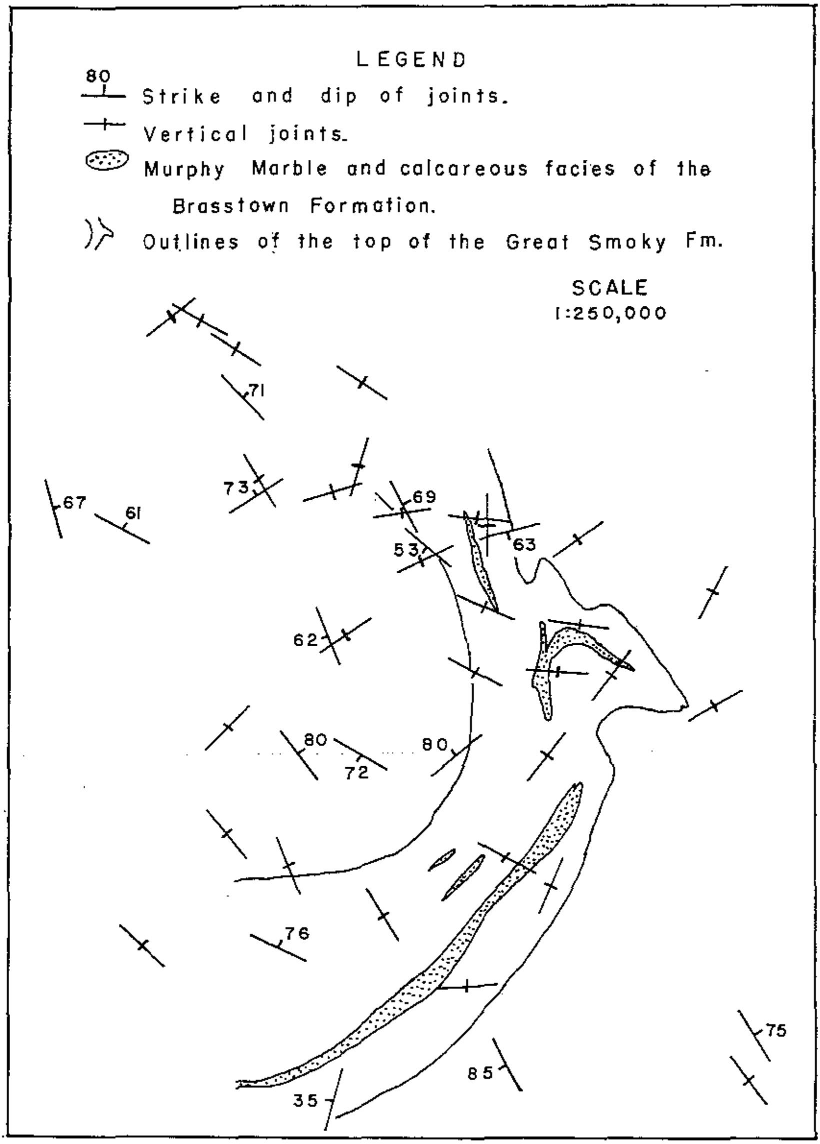

Fig. 7. Sketch map of joints in the vicinity of the Tate quadrangle. The map generalizes the orientations measured at 220 localities.

Petrofabric Studies

General remarks.—Fabric studies were made according to the conventional methods as described by Fairbairn (1949) and Knopf and Ingerson (1938). The location of the diagrams is shown in figure 10, page 67. The diagrams are compiled on Plate 10. (In the following discussion the diagrams on Plate 10 are referred to as D1, D2 etc.) The orientation arrows in the center of the diagrams indicate the strike and dip of the plane of projection. The mark is omitted on some diagrams for the sake of clarity if the relationship of the fabric to known megascopic planes such as schistosity is otherwise obvious. Some diagrams show girdle axes parallel to the arc-shaped trend of the syncline (L1). The projection of these axes on the diagrams is labeled "B". Other girdle axes are parallel to the cross-folds, and the projection of these axes is labeled "B' ".

Three tests were made to be sure a sufficient number of grains were counted from each thin section. The first test consisted of counting fifty grains from different parts of a thin section and then comparing diagrams of fifty grains with diagrams of four counts of fifty combined. The second test consisted of making separate fabric diagrams for the first 50 and the first 100 grains counted, and then combining these counts with all the grains counted in the section. Diagrams based on fifty grains show the same maxima as the diagrams based on 200 or more grains, but there are small differences in the distribution of the lower-valued contours. Diagrams based on 100 grains are essentially identical with diagrams based on 200 grains. A third test of the homogeneity of the fabric will be described with the calcite specimen from the Harrington quarry.

Mica fabric.—The mica fabrics are characterized by strong, single maxima, by strong maxima in partial girdles; and by maxima within complete girdles. The complete girdles occur in rocks which have been highly deformed as shown by intense crenulations, small folds, or by cataclastic textures. Cloos (1941, p. 48) has noted such a correlation between the intensity of deformation and the development of girdles in the Martic area of Pennsylvania.

D1 and D2 show the single, strong maxima. The one S-surface indicated by the mica in these diagrams is the bedding-schistosity surface (S1-S2) which is readily observed in the field. The distribution of poles is slightly spread out in D3, and more broadly drawn out in D4. The sample for D4 was collected about one mile north of the word "Marble" in the name Marble Hill on Plate I. Here there is a gentle, open fold as shown by a stereographic plot of the three beds whose dips are 22°, 14° and 19°. The horizontal projection of the fold axis is six degrees east of north and the plunge of the axis is ten degrees to the southwest. The fold axis is nearly parallel to the normal to the plane of projection of the thin section. A more complete girdle is shown in figure D5 which comes from one of the mylonitized rocks east of Marble Hill. The girdle axis (B') of D5 is parallel to the crenulation axes (L2) observed in nearby outcrops.

Two diagrams show the mica orientation in a fold which occurs in an outcrop about six feet square. This small fold is overturned to the southwest. D6 is from the upper limb of the fold, near the crest; D7 is from the overturned limb of the fold. The mica does not lie in the bedding-schistosity surface, but is nearly parallel to the axial plane of the fold. Weak girdles are developed about the fold axis which is parallel to the regional lineation (L2). The quartz fabric in this fold is shown in D13 which corresponds to D7, and D14 which corresponds to D6.

The most intense deformation is generally shown beginning east of Tate and continuing east of Marble Hill. Intense crenulations (L2) are found at a few places outside this area however. D8 is from one of these areas where the crenulations are marked, but not quite as prominent as those shown in plate 9, figure 2. The crenulation axes are parallel to the girdle axis. Cataclastic textures, common near Marble Hill, do not accompany the crenulations found in other parts of the quadrangle.

Quartz fabric.—D9 and D10 are of one specimen to show the orientation of the quartz in the lee of garnets (D10) versus the orientation of the quartz not in the lee of garnets (D9). A photomicrograph of this specimen is shown in figure 1 (Pl. 8). Only 73 grains could be counted in the lee of garnets, but this is probably a sufficient number as indicated by the tests cited above. There is little difference in the orientation of the quartz in the two diagrams. This, together with the lack of a strong preferred orientation in the two diagrams, suggests that recrystallization outlasted mechanical deformation at this location.

D11 is from the same rock as D8 and the quartz also shows a girdle developed around the lineation (L2) as an axis.

D12 is from the same rock as D3 and shows a very weak girdle inside the periphery.

D13 and D14 are from the fold sampled for the mica D6 and D7. A broad but distinct girdle is coincident with the fold axis (L2).

D15 shows the quartz grains associated with the mica of D4. A partial, or perhaps parts of two concentric girdles are present. The girdle axis is the fold axis defined for the mica diagram.

The quartz axes shown in D16 are from a crushed and sheared garnet-mica-schist pictured in figure 2, (Pl. 8). Neither the bedding nor the lineation could be measured in the field. However, the trend of the formations is to the northeast (Plate 1) in the area where the specimen was collected. The axis of the diagram also trends to the northeast.

All the quartz fabrics cited correlate very closely with the mica fabric in that quartz axes are dispersed where the mica shows a single prominent maximum, but the quartz shows girdles where mica shows girdles.

The correlation between the development of quartz and mica girdles and the intensity of crenulations (L2) shows the crenulations to be axes of folding in the Tate area. Ingerson (1940, p. 565) found fabrics in the Baraboo Quartzite very similar to the fabrics in the Tate area. He says, "This identity of quartz and mica fabric in the quartzite and schist, with the axis of all the girdles coinciding exactly with that of plications, leaves no doubt that the axis is one of folding."

Calcite fabric.—The calcite fabric in the marble from the Harrington quarry was investigated in detail (D17-D20). One thin section was cut perpendicular to the schistosity (D17 and D18). Another thin section was cut from the same hand specimen in the plane of the bedding (D19 and D20). Photomicrographs were taken of the two thin sections and tracings were made of the grain boundries. The horizontal projection and the plunge of the optic axis in each grain was plotted on the tracing of the grain (Fig. 8). Optic axes and lamellae $[01\bar{1}2]$ were measured in each thin section. The following can be seen from the measurements:

1. The calcite grains are inequant, and the larger dimensions lie in the plane of the schistosity (figure 8). Only 56 grains could be reached in the thin section cut parallel to the schistosity.

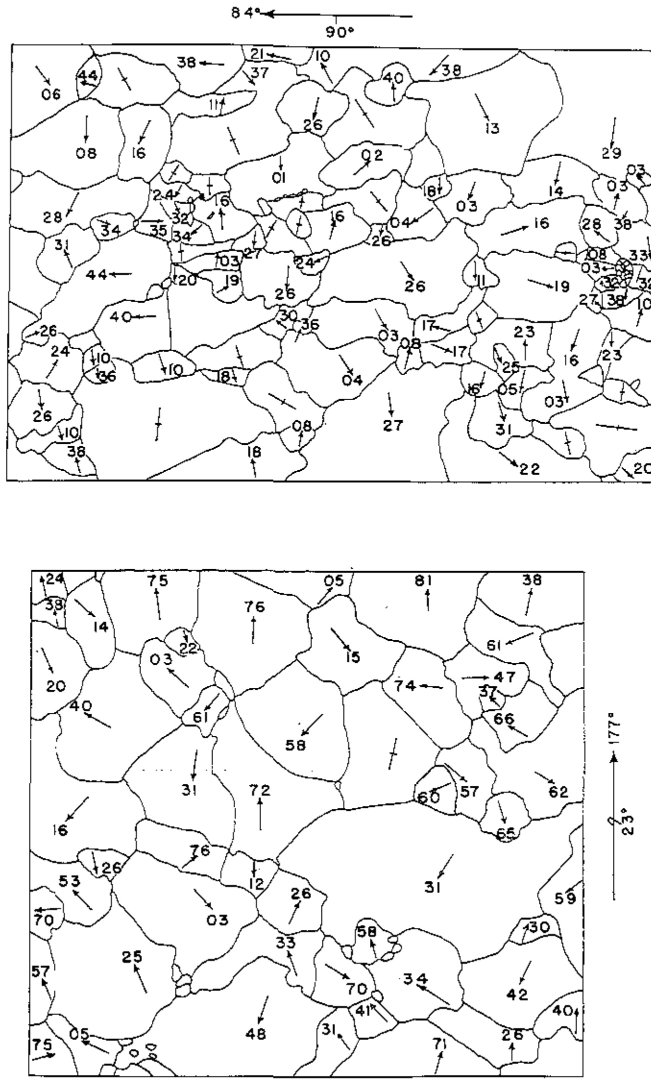

Fig. 8. Tracings of the grain boundaries in marble showing the orientations of the calcite optic axes. The thin section for the upper sketch was cut normal to the bedding, and the grains are plotted in D17. The thin section for the lower sketch is in the plane of the bedding, and the grains are plotted in D19. The marble is from the Harrington quarry, and the grain size is magnified approximately nine times.

2. Both large and small grains participate in the preferred orientations.
3. The concentrations of calcite optic axes nearly perpendicular to the bedding is obvious in both D17 and D19. Also, the separate concentrations of axes which lie nearly in the bedding plane can be seen in both diagrams. Thus the fabric is homogeneous over the domain of the hand specimen.
4. The prominent fabric element is a girdle axis parallel to the local fold axis as determined by the distribution of the stratigraphic units (Plate 1).
5. Rotation of D18 into the plane of D20 shows that nearly all the lamellae lie in or about the bedding plane. Almost no lamellae were found perpendicular or nearly perpendicular to the bedding.

Crenulations and fold axes follow two distinct trends in the Long Swamp Creek marble belt due east of Jasper (Plate 1). The largest observed folds are shown in plate 5, figure 2. The axes of these folds are nearly flat and trend approximately east-west parallel to the girdle axes of D21 and D22. The second trend of the fold axes is north-south. D23 and D24 show north-south girdle axes in the marble. It was necessary to count only 50 grains in this specimen because the girdle pattern was soon evident. The coincidence of girdle axes in the fabric with crenulations and folds is evident at many places in the quadrangle but is most striking at this locality.

The twin lamellae shown in D22 are unusual in having a maximum at right angles to the regional bedding, but the lamellae of D24 are in or near the plane of the bedding.

D25 and D26 are from the first of a set of specimens taken around the sickle-shaped pattern of marble called the Tate belt (page 27). These diagrams show a girdle axis on an azimuth of 168°, nearly parallel to the trend of the adjacent lithologies. Where no fold axes can be measured as at this locality the girdle axes can be related to the trend of the lithologies, and generally the girdle axes parallel the trend of the lithology (L1). Also, the maximum shows the lamellae to lie near, but not in, the bedding planes.

The next diagrams from the Tate belt, D27 and D28, also show a girdle axis parallel to the trend of the adjacent formations. Bedding is indistinct here. The plane labelled S1 is the orientation of broad bands of graphite. The plane labelled S1' is the orientation of the schistosity in nearby schists and the lamellae are concentrated near this plane.

D29, D30, D31, and D32 from two localities on the east side of the valley in the Tate belt show girdle axes parallel to the trend of the marble at these localities. The twin lamellae of the calcite grains tend to be concentrated in or near the bedding.

A girdle axis also parallels the east-trending portion of the Tate belt as shown in D33 and D34. The twin lamellae are spread broadly about the bedding.

The next sample, for D35 and D36, was taken where the Tate belt changes its trend from east-west to northwest-southeast. The bedding could not be determined here for two reasons. First, the marble is homogeneous and lacks any distinct bedding. Also, the vague bedding which does occur changes its attitude across distances of a few feet, perhaps because the marble is intricately folded. The diagrams differ from the other calcite diagrams in that the girdle is very incomplete. If this distribution of axes and lamellae can be considered a girdle, the axis trends about 72° east of north. The structure in the nearby rocks, which is most nearly parallel to this direction, is a lineation due to wrinkling of the schistosity in the overlying hornblende schist. The wrinkles have a horizontal projection 21° east of north and plunge to the southwest.

D37 and D38 show the fabric of the marble near the Cowart quarry. A broad, incomplete girdle of both calcite axes and poles to lamellae is present. The girdle axis trends about 48° east of north and is nearly horizontal. The lamellae are near, but not in the bedding plane.

A specimen from southwest of Ball Ground shows a partial girdle whose axis is parallel to the trend of the formations in the area (D39 and D40). The lamellae are concentrated in four maxima spread about the bedding.

ORIGIN OF THE OUTCROP PATTERN EAST OF TATE AND MARBLE HILL

Introduction

Several features must be kept in mind in synthesizing stratigraphic and structural data into a connected account of the origin of the complicated outcrop pattern east of Tate and Marble Hill.

1. The Murphy Syncline northeast of Ellijay follows a straight line for nearly seventy-five miles (figure 1).
2. South of Ellijay the trend of the syncline is S-shaped.
3. The arc-shaped trend of the syncline in the Tate quadrangle is a segment of the larger S-shaped bend.
4. Cross-folds (L2) lie across the trend of the syncline in the Tate quadrangle (figure 6).
5. Cataclastic textures are prominent near Marble Hill and to the east. Crenulations and small folds are most common in this area.
6. The boundary between the Great Smoky and Brasstown Formations southeast of Marble Hill is shaped like a "V" instead of conforming to the general arc-shaped trend of the syncline. A line bisecting the "V" trends northwest-southeast, nearly parallel to the cross-folds.

Attention is also directed to the position of several folds in the central and north central part of the quadrangle (Plate 1). An anticline in the Brasstown Formation disappears 1 ¼ miles due south of Nelson by plunging to the north. Southward, this anticline is flanked by two synclines of Andrews Schist. The western syncline contains scattered outcrops of a calcite-rich facies. To the north, at the little hill ½ mile northeast of the Cherokee quarry, the Brasstown Formation reappears as an anticline, again separating two synclines containing Andrews Schist and also Murphy Marble. The western syncline contains outcrops of a calcite-rich facies as it does south of Nelson. The strike of these folds is parallel with the major syncline from the southern end of the quadrangle up to the vicinity of Tate. Following the western syncline northward, the trend of the fold turns a little east of north, away from the regional trend of the syncline. Also, the Murphy Marble disappears to the north, in part by a gradation into schist, as can be seen at outcrops and inferred from a drill core, and perhaps also in part by lensing. Farther north the Andrews Schist disappears and about one mile farther northeast the strike (of the Great Smoky Formation) turns to the northwest and parallels the arc-shaped trend of the syncline.

The eastern syncline trends northward along the hill northeast

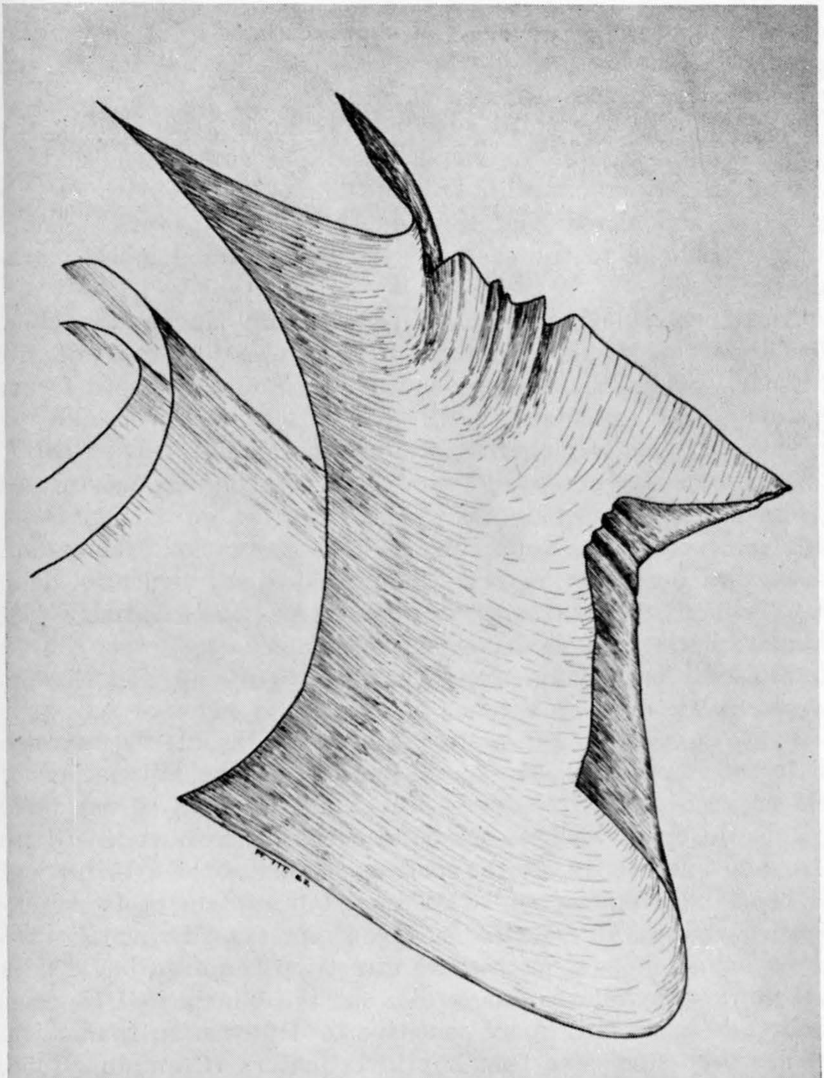

Fig 9. The shape of the cross-folded Murphy Syncline shown at a horizon near the middle of the Brasstown Formation, with the outcrop pattern of the Great Smoky and Hiwassee Formations shown by the arcs on the west (left).

of the Cherokee quarry, and then bends sharply to the east. At the center of curvature of this bend, small folds and crenulations (L2) are especially numerous. The syncline continues with an east-west trend for about 1 mile then bends to the southeast. At the center of curvature of this second bend a lineation of ridges in the planes of schistosity in hornblende schist dips to the southwest. A short distance to the southeast the plunge of the syncline brings the base of the marble and schist to the present erosion surface.

A portion of the third syncline of marble occurs along the southwestern edge of the metagabbro. The attitude of the bedding in schist and quartzite around the metagabbro outlines this syncline, and shows that it is doubly plunging, with a trend slightly oblique to the eastern syncline discussed in the paragraph above.

The spectacularly crumpled form of the Murphy Syncline, including the V-shaped outcrop pattern east of Tate, and the intense local crenulations, is shown diagrammatically in figure 9.

Explanation of the Structures

The shape and outcrop pattern of the syncline are interpreted to have been formed as follows:

The syncline was originally straight throughout its extent. A second period of deformation refolded the syncline along axes which trend northwest-southeast. As the second period of folding progressed, the side of the syncline which was convex to the east became intensely pinched (figure 9), and the enclosed rocks were crushed and granulated.

A gentle warp in the east-west trend of the marble between Tate and Marble Hill was mentioned in the fabric discussion of D4 (page 55) and D15 (page 56). This warp can be explained within the framework of the deformation plan shown in figure 9 and outlined above. As the concave portion of the syncline was pinched into the shape of a "V", resistance to the eastward extension of the "V" effected enough compression to gently warp the syncline along a north-south direction. The mica in D4 does not show a well-developed girdle, but the quartz in D15 does. Quartz is apparently more sensitive to deformation than mica, as has been suggested by many investigators (Crampton, 1958, p. 28).

Thus the outcrop pattern, the evidence of local mylonitization and the fabric girdles all combine to show that the structure east of Tate is best explained as the result of a second period of deformation which cross-folded the syncline. The deformation was sufficiently intense to produce intense pinching and plication of the rocks affected and to cause noteworthy changes in their fabric. The concept of a "Whitestone thrust" is not needed to explain these structural features—indeed the structures themselves are strongly at variance with this concept.

RESULTS OF RECONNAISSANCE WORK

The rock units beneath the Great Smoky Formation were investigated, and the Murphy Syncline was traced into the Waleska quadrangle. No detailed mapping was done in these areas, and so the results of the work are provisional.

The Hiwassee and Canton Schists

A graphitic schist underlies the Great Smoky Formation on the western limb of the Murphy Syncline. Bayley called this schist the Hiwassee Schist, a formation named by Keith (1904) for exposures on the Hiwassee River, Tennessee. In Tennessee, Keith mapped the Hiwassee Formation under both the Cochran Conglomerate and the Great Smoky Formation, which he thought equivalent. King et. al. (1958, p. 961) suggest that the name "Hiwassee" be abandoned because, "The Hiwassee was named for a locality in the Murphy quadrangle, for which no description was published, and the name was used so confusingly elsewhere that it is properly abandoned". It should be emphasized that the Hiwassee Schist shown on Plate I is copied directly from Bayley's map and does not represent the changes in usage of the term Hiwassee that have been made by King and others. The name "Hiwassee Schist" on Plate I probably should be changed to "Canton Schist" which is also a graphitic schist found in the southeastern corner of the quadrangle. Bayley named it the Canton Schist for its exposures near Canton (figure 1) and said (1928, p. 43) that it is "... so remarkably similar to the Hiwassee schist. . .that the two are thought to be parts of the same formation". Yet by his mappng the Hiwassee Schist is of Cambrian age, and is separated from the Precambrian (?) Canton Schist by the Whitestone thrust.

The Whitestone thrust is not necessary to explain the geology of the Tate quadrangle, and the thrust very likely does not exist at all (page 5). Also much of what has been called the Carolina Gneiss belongs to the Great Smoky Formation (as was suspected by Bayley, p. 56). Reconnaissance work suggests that the metagraywackes and schist adjacent to the Canton Schist belong to the Great Smoky Formation. Hence, the Hiwassee and Canton Schists are probably the same, and the repetition of the Canton Schist in the southeastern part of the quadrangle is due to folding.

A thin section of a specimen from the Hiwassee Schist shows crenulations in the foliation and a folded quartz vein with tension fractures (Pl. 11, fig. 1). These minute fabric elements and a fracture cleavage which occurs in some of the nearby rocks are not common in the rocks of the Murphy Syncline which were investigated in more detail. The texture of the Hiwassee Schist may be due to its location near the Cartersville thrust shown on the Geologic Map of Georgia (1939).

A thin section of the Canton Schist (Plate 11, fig. 2) shows garnets with a helicitic texture. Further study of the direction sense of the rotation of S-planes in these garnets would be helpful in outlining the deformation plan in this part of the quadrangle.

The Salem Church Granite

Many varieties of rock occur in the area mapped by Bayley (1928) as the Salem Church Granite. Graphitic schist, sericite schist, pure quartzite, pyrite-rich quartzite and feldspathic (perthite) quartzite are all present along the Salem Church Anticline (figure 2). The author found no granite nor any rocks which have unequivocally been derived from a granite. The feldspathic quartzite may have been a granite, but a few observations showed the perthite content ranges from zero to thirty-five percent, so that the original rock was probably a sandstone, locally arkosic. All the rocks observed are cataclastically granulated and the Cartersville thrust may complicate the structures and stratigraphy of the area.

The High Tower Granite

The High Tower Granite consists of a granoblastic to slightly schistose mosaic of quartz, microline, and plagioclase with minor biotite and muscovite. Good exposures of the granite are rare, and it was impossible to determine the relationship of the granite with the surrounding schists and gneisses. Bayley's map shows the granite cutting the regional structures and he believed the granite was intruded into the older metamorphic rocks. The author found insufficient evidence to support or deny his conclusion.

The Cartersville Thrust and the Tectonite Frontier

The Cartersville and Great Smoky faults (figure 2) are part of a fault zone which extends the length of the Blue Ridge Moun-

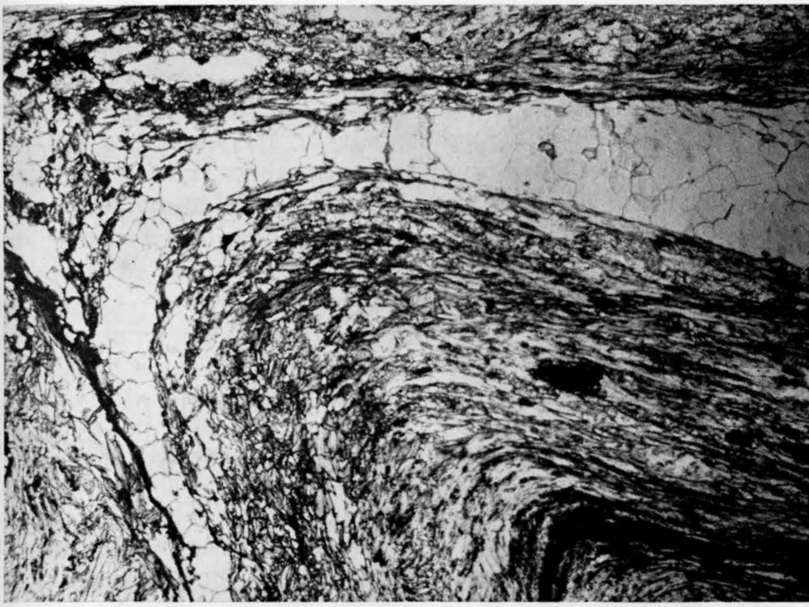

Fig. 1. Folding in the Hiwassee Schist, one mile due north of Salem Church. Note the fan-shaped fractures in the quartz vein at the apex of the fold. Photomicrograph, plain light, X25.

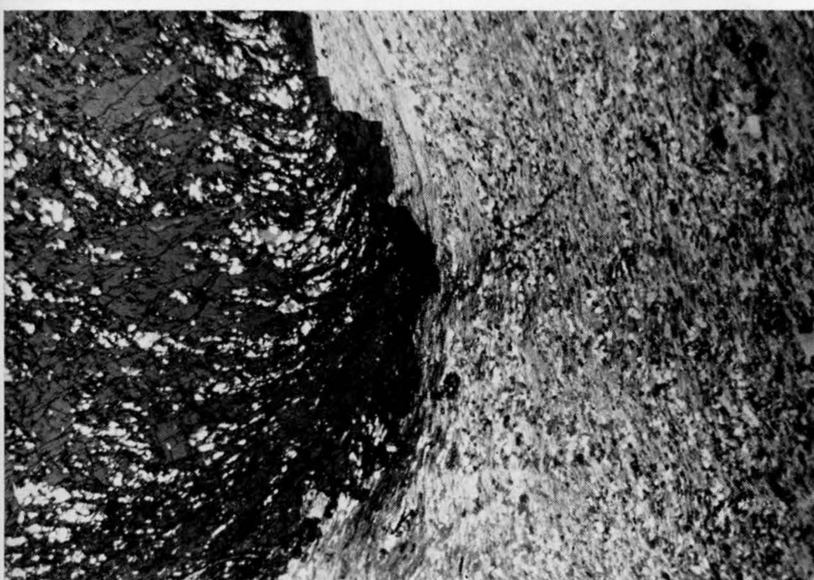

Fig. 2. Canton Schist showing inclusions in garnet that indicate rolling, one-half mile southeast of Liberty Church. Photomicrograph, crossed nicols, X6.

PLATE 11

tains and separates older crystalline rocks to the east from fossil-bearing Paleozoic rocks to the west. Cloos (1957) has shown that through the central portion of this zone, in Tennessee and Virginia, crystalline rocks are in contact with essentially unmetamorphosed Paleozoic rocks, but in Maryland the eastern members of the Paleozoic section have been metamorphosed. The boundary between the metamorphosed and unmetamorphosed Paleozoic rocks has been called the "tectonite frontier" by Fellows (1943). The southern end of the tectonite frontier passes beneath the crystalline rocks near the Potomac River. East of Bolivar (figure 2) the tectonite frontier reappears from beneath the Cartersville Thrust and the Paleozoic rocks show lineations, fracture cleavage and other evidence of metamorphism.

The existance of the Cartersville thrust in the Cartersville area has been questioned by Kesler (1950). He reviewed the problem of the fault and pointed out difficulties in its mapping by earlier workers. A deflection of the fault by cross-folding might account for the discrepancies in these interpretations. Future workers in the area should consider the possibility that the thrust has been cross-folded; that the little eastward bulge in the thrust east of Bolivar (figure 2) actually extends into the Tate quadrangle; and that the fault could be outlined around the Salem Church Anticline by mapping zones of mylonitization.

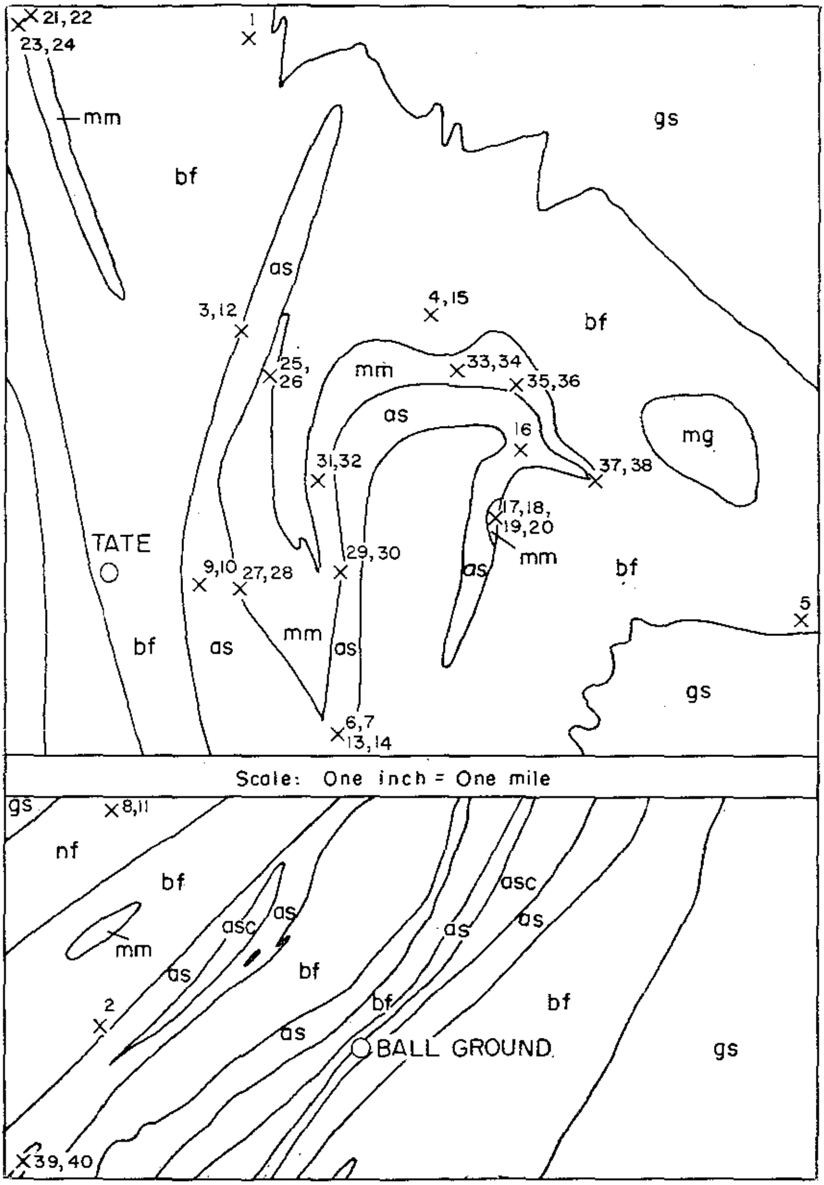

Fig. 10. Sketch maps showing location of petrofabric diagrams.

SUMMARY OF RESULTS AND CONCLUSIONS

1. Two hundred square miles of the Appalachian Piedmont in Georgia were mapped and an additional three hundred square miles were studied by reconnaissance methods.

2. Three major folds have been traced-out within the Tate and adjacent quadrangles; the Murphy Syncline, the Salem Church Anticline, and a syncline near Bolivar. Another anticline probably lies east of the Murphy Syncline.

3. Both limbs of the Murphy Syncline were traced through the Ellijay and Tate quadrangles to the vicinity of Waleska, Georgia, although previous workers had assumed that the eastern limb was cut off by the Whitestone thrust.

4. The intricate outcrop pattern in the Murphy Syncline from Tate to Marble Hill and eastward beyond the edge of the Tate quadrangle is due to cross-folding. Mylonitization and the development of fabric girdles by rotation around the fold axes accompanied cross-folding.

5. The Whitestone thrust of LaForge and Phalan does not exist in the Tate quadrangle, and no evidence of it was found at its type locality in Georgia.

6. Interbedded gradational contacts occur between most of the stratigraphic units even where they were formerly thought to be separated by the supposed Whitestone thrust fault.

7. Areas of marble within the Tate quadrangle have been divided into those which belong to the Murphy Formation and those which are calcareous members of the Andrews Formation.

8. Rocks previously mapped as the Roan Gneiss have been differentiated. They include a uralitic gabbro and a hornblende schist. The hornblende schist is of sedimentary origin and has been named the Marble Hill Hornblende Schist, a new formation between the Murphy Marble and the Andrews Schist.

9. Graphitic schists previously thought to belong to the Nantahala Formation are mostly graphitic parts of the Andrews Schist. Other graphitic schists north of the quadrangle, as at Whitestone, Georgia, may be graphitic facies of the Brasstown Formation.

10. Several kinds of calc-silicate rocks have originated from the metamorphism of calcareous concretions and beds.

11. Pegmatites, quartz veins, and gabbro were probably introduced during cross-folding late in the metamorphic history of the area.

12. The Salem Church Granite and the High Tower Granite include complex assemblages of rocks which perhaps constituted part of the basement on which the rocks of the Murphy Syncline were deposited.

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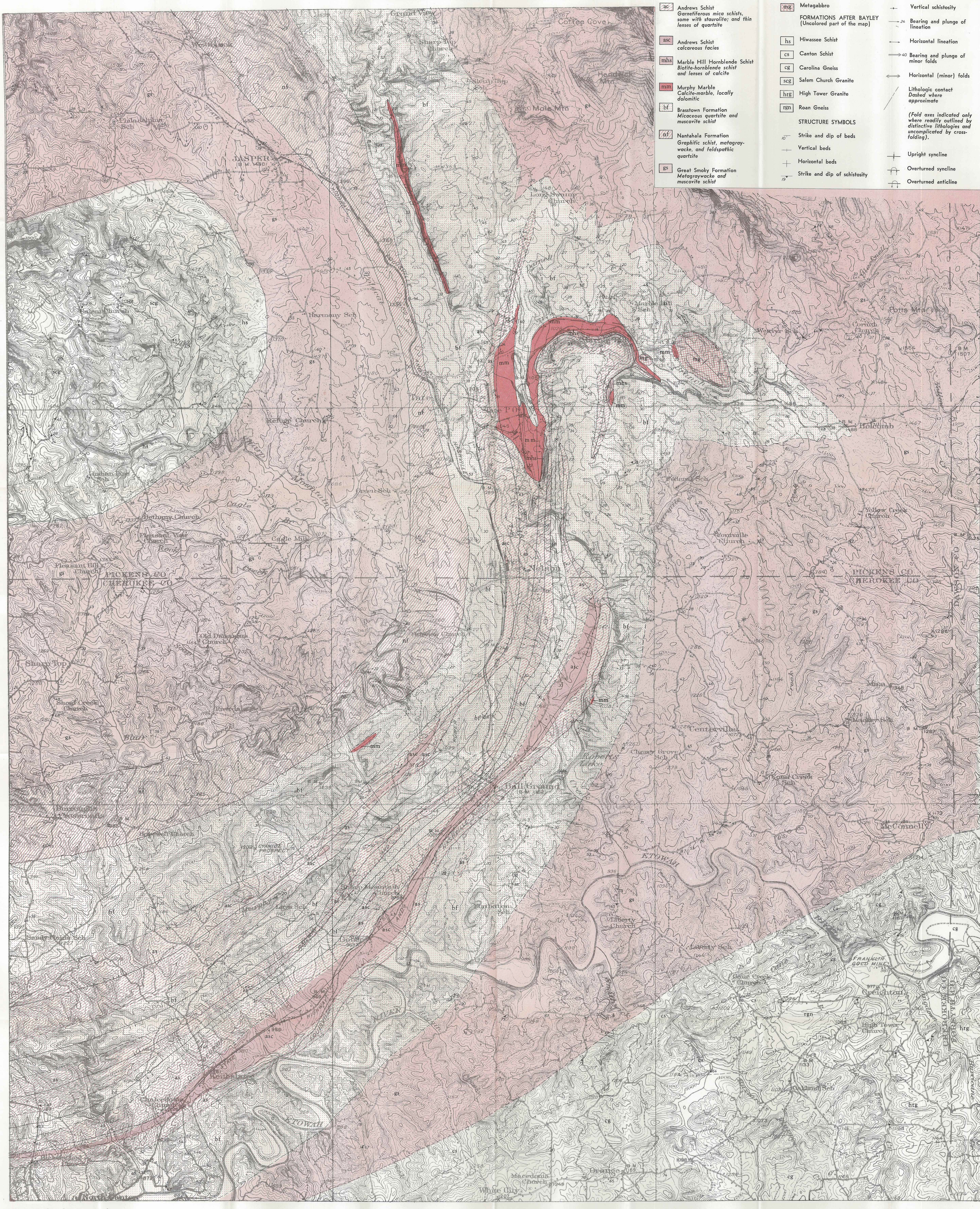
PLATE I

GEOLOGIC MAP OF THE TATE QUADRANGLE, GEORGIA



Topographic base map by
U. S. Geological Survey, 1926.

Scale 1:31,250

1 1/2 0 1 2 Miles

Contour interval 20 feet.

Geologic map (uncolored part) after W. S. Bayley, 1928
Geologic map (colored part) by W. M. Fairley, 1962

Diagram	Mineral	Formation	Rock Type	No. of grains measured	Fabric element measured	Contours in percent
1	biotite	Brasstown	quartz schist	100	cleavage poles	35,25,10,1
2	muscovite	Brasstown	micaceous quartzite	100	cleavage poles	30,20,10,1
3	biotite	Andrews	micaceous quartzite	150	cleavage poles	18,15,10,5,0.75
4	muscovite	Brasstown	quartz schist	150	cleavage poles	20,15,10,5,2,0.75
5	biotite	Brasstown	quartz-oligoclase schist	200	cleavage poles	8,6,4,2,0.5
6	biotite	Andrews	micaceous quartzite	150	cleavage poles	15,10,7.5,2.5,1
7	muscovite	Andrews	micaceous quartzite	200	cleavage poles	15,10,7.5,2.5,1
8	biotite	Nantahala	biotite quartzite	100	cleavage poles	15,10,5,1
9	quartz	Andrews	garnet-mica schist	200	optic axes	4,3,2,1
10	quartz	Andrews	garnet-mica schist	73	optic axes	6,4,3,2,1
11	quartz	Nantahala	biotite quartzite	200	optic axes	7,6,5,4,3,2,1
12	quartz	Andrews	micaceous quartzite	200	optic axes	4,3,2,1,0.5
13	quartz	Andrews	micaceous quartzite	200	optic axes	4,3,2,1,0.5
14	quartz	Andrews	micaceous quartzite	200	optic axes	6,5,3,2,1,0.5
15	quartz	Brasstown	quartz schist	166	optic axes	7,6,5,4,3,2,1
16	quartz	Andrews	garnet-quartz schist	200	optic axes	6,5,4,3,2,1,0.5
17	calcite	Murphy	marble	106	optic axes	8,6,4,2,1,0.8
18	calcite	Murphy	marble	178	lamellae poles	6,5,4,3,2,1
19	calcite	Murphy	marble	56	optic axes	10,8,6,4,3,2
20	calcite	Murphy	marble	106	lamellae poles	5,4,3,2,1
21	calcite	Murphy	marble	190	optic axes	5,4,3,2,1
22	calcite	Murphy	marble	208	lamellae poles	4,3,2,1
23	calcite	Murphy	marble	50	optic axes	10,8,6,4,2
24	calcite	Murphy	marble	93	lamellae poles	6,5,4,3,2,1
25	calcite	Murphy	marble	150	optic axes	6,5,4,3,2,1
26	calcite	Murphy	marble	224	lamellae poles	6,5,4,3,2,1
27	calcite	Murphy	marble	114	optic axes	4,3,2,1
28	calcite	Murphy	marble	100	lamellae poles	6,5,3,1
29	calcite	Murphy	marble	110	optic axes	6,5,4,3,2,1
30	calcite	Murphy	marble	100	lamellae poles	9,7,5,3,1
31	calcite	Murphy	marble	230	optic axes	6,5,4,3,2,1
32	calcite	Murphy	marble	100	lamellae poles	10,8,6,4,2,1
33	calcite	Murphy	marble	200	optic axes	7,6,5,4,3,2,1
34	calcite	Murphy	marble	100	lamellae poles	5,3,1
35	calcite	Murphy	marble	170	optic axes	9,7,5,3,1
36	calcite	Murphy	marble	218	lamellae poles	6,5,4,3,2,1
37	calcite	Murphy	marble	133	optic axes	4,3,2,1
38	calcite	Murphy	marble	235	lamellae poles	5,4,3,2,1
39	calcite	Andrews	micaceous marble	100	optic axes	7,6,5,4,3,2,1
40	calcite	Andrews	micaceous marble	118	lamellae poles	5,4,3,2,1

PLATE 10