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Garland Peyton, Director

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GEOLOGY AND MINERAL RESOURCES OF THE THOMASTON QUADRANGLE, GEORGIA

By

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LETTER OF TRANSMITTAL

Department of Mines, Mining and Geology

Atlanta, May 7, 1952

To His Excellency, Herman Talmadge, Governor
Commissioner Ex-Officio, State Division of Conservation

Sir:

I have the honor to submit herewith Georgia Geological Survey Bulletin No. 59, "Geology and Mineral Resources of the Thomaston Quadrangle, Georgia" by Dr. James Wood Clarke, Professor of Geology, Vanderbilt University.

The field work for this report was done at small expense to the State, and the report covers in detail the area of the Thomaston quadrangle, about 250 square miles. The report is a very thorough one and its technical character makes it of special value to the trained geologist. The area involved embraces one of the outstanding sheet mica districts of the country, thus this report will serve as a useful guide to mica prospectors. The final sections on economic minerals include a review of mica, quarry sites, graphite, iron ore, sand and gravel, kyanite, springs, and recreational areas.

Respectfully,

GARLAND PEYTON
Director

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ABSTRACT

Within the Thomaston quadrangle are three belts of rocks, each separated from the other by a thrust fault.

Biotite gneiss underlies the area north of the Towaliga fault.

South of the Towaliga fault and north of the Goat Rock fault is the Wacoochee belt. The oldest unit in this belt is the Woodland gneiss, which is a biotite granite gneiss. The Woodland gneiss is overlain unconformably by the Hollis quartzite and the Manchester formation, metasedimentary formations which together compose the Pine Mountain group.

Intrusive into the Manchester formation is a sill-like batholith of garnetiferous biotite granite for which the name Jeff Davis granite is proposed. Marginal to this batholith is a broad belt of migmatite. The migmatization is regarded as having been effected by the batholith.

Intrusive into the Jeff Davis granite and surrounding migmatite are rocks of the charnockite series. All members of the series from hypersthene gabbro to hypersthene granite are present. These rocks are characterized by remarkable single and double coronas. The coronas are unique in that they occur not only in subsilicic and intermediate rocks but also in granite, an occurrence not previously reported. Also unique is the occurrence of coronas around apatite.

South of the Goat Rock fault is a terrane made up of biotite-oligoclase gneiss and epidote amphibolite gneiss. Intrusive into these gneisses is a hornblende-biotite granite.

Both the Towaliga fault and the Goat Rock fault are marked by a broad zone of distributive movement along which the rocks have been mylonitized and otherwise deformed. The interpretation is suggested that the Towaliga fault and the Goat Rock fault are parts of the same thrust fault and that the northwest dip of the Towaliga fault is due to subsequent folding. According to this interpretation the Wacoochee belt is a window.

The topography of the Thomaston quadrangle is well-dissected. There are remnants of a post-mature erosion surface

younger than the sub-Cretaceous peneplain. The Flint River probably was superposed into its present cross-axial position from a sedimentary cover.

A final chapter is devoted to the mineral resources of the quadrangle. It is hoped that this rather complete discussion of the geology along with the accompanying geologic map will be of continual use to future prospectors in this district.

THE GEOLOGY AND MINERAL RESOURCES OF THE THOMASTON QUADRANGLE, GEORGIA[1]

Purpose of the Investigation

The purpose of this investigation is to describe and interpret the geology of the Thomaston quadrangle, Georgia. The areal geology was mapped during the summer months of 1948 and 1949. The petrography and writing were done during the academic year 1949-1950 at Yale University, New Haven, Connecticut.

Acknowledgments

The writer gratefully acknowledges the defrayment of field expenses for this study by the Department of Mines, Mining and Geology of the State of Georgia. Captain Garland Peyton, Director, showed every consideration. Dr. A. S. Furcron, Assistant State Geologist, accompanied the writer in the field several days, and his interest in the geologic problems of the area helped clarify many points; also, he critically read the manuscript and saw it through the press. Dr. John Rodgers and Dr. Elenora Bliss Knopf also have taken a great interest in the problem both in the field and at New Haven. Fred M. Bell of Atlanta assisted the writer for two days on a boat trip on the Flint River.

Dr. Adolph Knopf, under whose direction this study was made, showed an unfailing interest both in the field and at New Haven. He was a constant guide and inspiration.

The writer wishes to acknowledge gratefully the aid rendered by these people and by many others.

Location

The Thomaston quadrangle is bounded by the longitude lines 84° 15′ W and 84° 30′ W and by the latitude lines 32° 45′ N and 33° 0′ N. The northern edge of the quadrangle is 62 miles south of Atlanta, Georgia, on U. S. Route 19. The dimensions of the quadrangle are 14.5 miles (east-west) by 17.3 miles (north-south), and the area is about 250 square

[1]A dissertation presented to the Faculty of the Graduate School of Yale University in candidacy for the degree of Doctor of Philosophy.

miles. It takes in about three-fifths of Upson County, about one-tenth of Talbot County and small portions of Pike and Lamar Counties.

The Thomaston quadrangle lies along the southern margin of the Appalachian Piedmont province. Cretaceous sediments extend to within less than two miles of the southern edge of the quadrangle.

Topography and Drainage

The greatest relief in the area is in the northern and western portions. Pine Woods Ridge, Brooks Mountain, Dorster Mountain, Bull Trail Mountain and Indian Grave Mountain all have altitudes over 1100 feet. The highest point on both Dorster Mountain and Indian Grave Mountain is 1262 feet; these are the highest points in the quadrangle. These ridges and knobs are held up by quartzites and are part of a series of similar hills and ridges that extends from near Barnesville, Georgia, southwestward through the Thomaston quadrangle and into Alabama.

The topography of the central portion of the quadrangle is gently rolling. The relief is generally about 100 feet and the altitudes are between 600 and 800 feet.

Along Potato Creek south of its junction with Baroucho Creek and along Lazer Creek and Flint River, the relief is generally more than 200 feet. Flint River leaves the quadrangle at 350 feet elevation, which is the lowest point in the quadrangle.

There are no steep slopes in the area except where Flint River has cut through quartzite ridges. At Spewrell Bluff and Tally Gap the slopes are more than 45°. These gorges are most picturesque.

Most of the drainage of the area flows through Potato Creek and Lazer Creek into Flint River. The rest of the drainage flows directly into the Flint River through smaller streams. Just south of the quadrangle Flint River enters the Atlantic Coastal Plain and flows directly south to join the Chattahoochee River about 70 miles north of the Gulf of Mexico. On joining, these two rivers become the Apalachicola River.

Geography

The Thomaston quadrangle is an interesting example of the influence of lithology on the geography and culture of an area. The soil that developed from the granitic terrane of the central and southern parts of the quadrangle was originally richer than the soil that developed from the schist terrane of the northern and northwestern parts of the quadrangle. The richer soils were farmed intensively under a plantation economy. Shortsighted farming methods eventually rendered these soils poorer than the soils of the schist terrane. In the meantime the soils of the schist terrane were being farmed by small landholders. Their methods were not as harmful to the soil as those of the large landholders on the granitic terrane.

The areas of now relatively poorer soil of the granitic terrane were abandoned by farmers, and the land was given over to timber. In this way the fertility of the soil is being restored. The land is still in the hands of large landholders. The areas of now relatively richer soil of the schist terrane are still farmed by small landholders. In these areas farming is diversified and progressive. Peppers, cotton, peaches, turkeys, and cattle of the best quality are produced.

The abandonment of the granitic terrane by farmers was coincident with the growth of the textile industry in East Thomaston and Silvertown. These people gave up a rather hard and insecure life as farmers in favor of the higher income and greater leisure of the factory worker.

Previous Work on the Area

Before this study was made, all geologic investigation within the Thomaston quadrangle had been of a specialized economic nature or on a rapid reconnaissance basis. Brief mention of the formations of the area was made by Galpin (1915, pp. 74-76), Adams (1930, pp. 271-279), and Crickmay (1935, p. 32).

The Warm Springs quadrangle, which adjoins the Thomaston quadrangle on the west, was studied intensively by Hewett and Crickmay (1937). This investigation was made in conjunction with their investigation of the warm springs of the region.

The Thomaston quadrangle and the area to the east were the scene of an active development of sheet mica deposits during World War II. A survey of the pegmatites carrying commercial mica was made by Furcron and Teague (1943, pp. 19-48).

General Geology

The Thomaston quadrangle lies in the Greenville Plateau of the Central Upland of Georgia. The quadrangle is underlain by three separate and distinct belts of rocks, each separated from the other by a thrust fault.

In the northwest corner of the quadrangle an area of less than one square mile is underlain by biotite gneiss. This terrane is separated from the rocks of the Pine Mountian group to the south by the northwest-dipping Towaliga fault.

Between the Towaliga fault on the north and the Goat Rock fault on the south is the Wacoochee belt, a terrane composed of igneous and metasedimentary rocks. This terrane underlies 210 square miles within the quadrangle. The petrography and geologic history of these rocks are given detailed attention in this report because of their geologic and economic importance.

The oldest formation in the Wacoochee belt is the Woodland gneiss. It is overlain unconformably by the Hollis quartzite which is in turn overlain conformably by the Manchester formation. The Manchester formation consists of a lower schist member, a middle quartzite member, and an upper schist member. The Hollis quartzite and the Manchester formation together form the Pine Mountain group.

Intrusive into the Manchester formation is a batholith of garnetiferous biotite granite for which the name Jeff Davis granite is proposed. Along the margins of this body is a wide belt of migmatization, and it is principally within this belt that the commercial mica-bearing pegmatites of the Thomaston area occur.

Intrusive into the Jeff Davis granite and surrounding migmatite are rocks of the charnockite series. All members of the series from hypersthene gabbro to charnockite are present.

South of the Goat Rock fault is an area of 40 square miles that is underlain by biotite-oligoclase gneiss and epidote amphibolite gneiss. Intrusive into these gneisses is a hornblende-biotite granite.

Both the Towaliga fault and the Goat Rock fault are marked by a wide zone of distributive movement. Mylonite is found in both zones. That the Towaliga fault dips to the northwest suggests an interesting interpretation of the regional structure. According to this interpretation the Goat Rock fault and the Towaliga fault are portions of a single thrust, which has been folded; and subsequently erosion has breached the thrust plate, exposing the rocks of the Wacoochee belt as a window.

DESCRIPTION OF THE FORMATIONS

General Statement

In this chapter a historical review is given for each unit. This is followed by sections on Areal Distribution, Weathering Features, Petrography, Structure, Genesis and Age.

The sections on structure discuss features characteristic of the several units. Since folding and faulting are not characteristic of any particular unit, they are discussed separately in the chapter on Structure.

None of the rocks of the quadrangle contain fossils, nor can they be correlated with any fossil-bearing formation. Therefore there is no positive evidence as to age. However, the absence of fossils and the metamorphosed nature of these rocks indicate that they are pre-Cambrian.

Biotite Gneiss

The area north of the Towaliga fault is underlain by a belt of rocks which is designated as Carolina series on the State Geologic Map. These rocks underlie a large area in the Warm Springs quadrangle to the west where they have been described briefly by Hewett and Crickmay (1937, p. 26).

Within the Thomaston quadrangle these rocks underlie less than one square mile. There is but one exposure and it is a deeply weathered road cut. Here the rock is principally a biotite gneiss. The foliation is contorted and exhibits no preferred orientation. Cutting the gneiss are pegmatites and quartz veins.

Table of Formations

Age	*Name*			*Description*
PRE-CAMBRIAN (?)	NORTH OF THE TOWALIGA FAULT			
	Biotite gneiss			Biotite gneiss cut by pegmatites and quartz veins. Forms hanging-wall of Towaliga fault.
	WACOOCHEE BELT (area between Towaliga fault and Goat Rock fault)			
	Charnockite series			All members of series from hypersthene gabbro to charnockite are represented. Intrusive into Jeff Davis granite and schist-gneiss migmatite.
	INTRUSIVE CONTACT			
	Jeff Davis granite			Garnetiferous biotite granite intrusive into metasediments overlying quartzite member of Manchester formation.
	INTRUSIVE CONTACT			
	Schist-gneiss migmatite			Mixed igneous and metasedimentary rocks marginal to Jeff Davis granite.
	PINE MOUNTAIN GROUP	Manchester Formation	Upper schist member	Mica schist and feldspathic mica schist. Average thickness is 1500 feet.
	PINE MOUNTAIN GROUP	Manchester Formation	Quartzite member	Pure and impure quartzite. Thickness ranges from 200 to 800 feet.
	PINE MOUNTAIN GROUP	Manchester Formation	Lower schist member	Kyanite-muscovite schist and biotite schist. From 1200 to 3000 feet thick.
	PINE MOUNTAIN GROUP	Hollis quartzite		Pure and impure quartzites. Thickness ranges from 800 to 1100 feet. Overlies Woodland gneiss unconformably.
	Woodland gneiss			Biotite granite gneiss. Basement for Wacoochee belt.
	SOUTH OF THE GOAT ROCK FAULT			
	Hornblende-biotite granite			Principally biotite granite. Intrusive into biotite-oligoclase gneiss and epidote amphibolite gneiss.
	INTRUSIVE CONTACT			
	Biotite-oligoclase gneiss and epidote amphibolite gneiss			Alternate belts of biotite-oligoclase gneiss and epidote amphibolite gneiss which grade into each other. Thrust from southeast onto rocks of Wacoochee belt.

Since this unit is so poorly represented within the Thomaston quadrangle, the writer feels that any statement concerning origin or correlation on his part is not justified.

WOODLAND GNEISS

Introduction

The area between the Towaliga fault on the north and the Goat Rock fault on the south is known as the Wacoochee belt. The Woodland gneiss, which is principally a biotite granite gneiss, forms the base of the stratigraphic column in this belt.

Historical Review

The Woodland gneiss was named for the town of Woodland in the Warm Springs quadrangle, Georgia, by Hewett and Crickmay (1937, p. 29). Their report contains the only description of the unit as such in the literature. On the State map it is denoted as augen gneiss and is not distinguished from the terranes that are differentiated as Jeff Davis granite and schist-gneiss migmatite in this report.

Areal Distribution

In the Thomaston quadrangle the Woodland gneiss underlies two separate areas along the western part of the quadrangle. The southern area is about 0.7 square miles and the northern about 1.4 square miles. Fresh exposures can be seen in Pleasant Valley. However, much better exposures occur in The Cove, which lies just west in the Warm Springs quadrangle.

Weathering Features

The Woodland gneiss is very susceptible to weathering, and fresh outcrops are therefore generally confined to the bottoms of valleys that are being down-cut by erosion. The rock in fresh outcrop is slabby or consists of angular boulders.

The contact between the Woodland gneiss and the overlying Hollis quartzite is exposed at several places, but the gneiss at the contact is deeply weathered without exception. This deep weathering may be attributed to the relatively greater susceptibility to weathering of the feldspathic gneiss in comparison to the quartzite. The quartzite inhibits mass-wasting to such an extent that by the time any of the gneiss has been uncovered by erosion, it had long since become deeply weathered.

Petrography

A re-examination of the Woodland gneiss in the Warm Springs quadrangle in conjunction with its study in the Thomaston quadrangle revealed that in addition to the typical gneiss some schist is present. Only the gneiss occurs in the Thomaston quadrangle, however, and it alone is described in this section.

In all specimens examined the fabric is allotriomorphic; only biotite exhibits crystal faces. The average grain size is 0.1 mm. to 0.3 mm., though there are a few scattered grains of microcline which are 1 mm. to 5 mm. in width. These larger grains may be phenocrysts.

Plagioclase generally makes up less than one percent of the rock. In a specimen containing a larger amount (about 15%) the composition is An_{30}. The potassium feldspar is microcline; all grains exhibit well-developed grid-twinning. A few grains, particularly the larger ones, are microperthitic.

Biotite is the principal varietal mineral, though muscovite is present in some specimens. Garnet occurs as isolated grains. Accessory minerals include zircon, apatite, sphene, and ilmenite. Myrmekite is generally well-developed. Quartz shows strain in all specimens.

The Rosiwal analysis of a typical specimen of the Woodland gneiss is given in Table I (Spec. 1).

Structure

The Woodland gneiss as seen in hand specimen has a moderate foliation produced by parallelism of the mica flakes. This parallelism is also very marked as seen in thin-section.

Since the important relationship between the Woodland gneiss and the overlying Hollis quartzite cannot be determined within the Thomaston quadrangle, it is necessary to consider a portion of the Warm Springs quadrangle. In Plate I the geology of The Cove and surrounding area is reproduced from the map of Hewett and Crickmay (1937, Plate III). The structure of the Woodland gneiss within The Cove is characterized by:

Table I

	Spec. 1
Microcline	44%
Quartz	43
Muscovite	5
Biotite	8
Others	tr[1])

[1]) Plagioclase, garnet, zircon, ilmenite, and sphene.

Spec. 1 Woodland gneiss. Pleasant Valley .5 miles northwest of Spring Mountain.

1. A regional foliation with a strike generally N70°E and a dip to the south.

2. A quaquaversally dipping foliation near the contact with the overlying quartzite. This foliation is parallel to the contact and to the bedding and schistosity of the quartzite. Also both gneiss and quartzite are sheared at the contact.

Since the N70°E foliation of the central portion of the gneiss does not extend into the quartzite, it must have been imposed on the gneiss before the quartzite was deposited. The discordance between the two units is therefore of the nature of an unconformity.

The quaquaversally dipping foliation of the gneiss near the contact is probably related to the shearing in the zone along the contact. The shearing is probably related to the same deformation that produced doming in the gneiss.

Genesis

Petrographically the Woodland gneiss is like a typical granite. However, it is too sparingly and too poorly exposed to furnish any positive information about its origin.

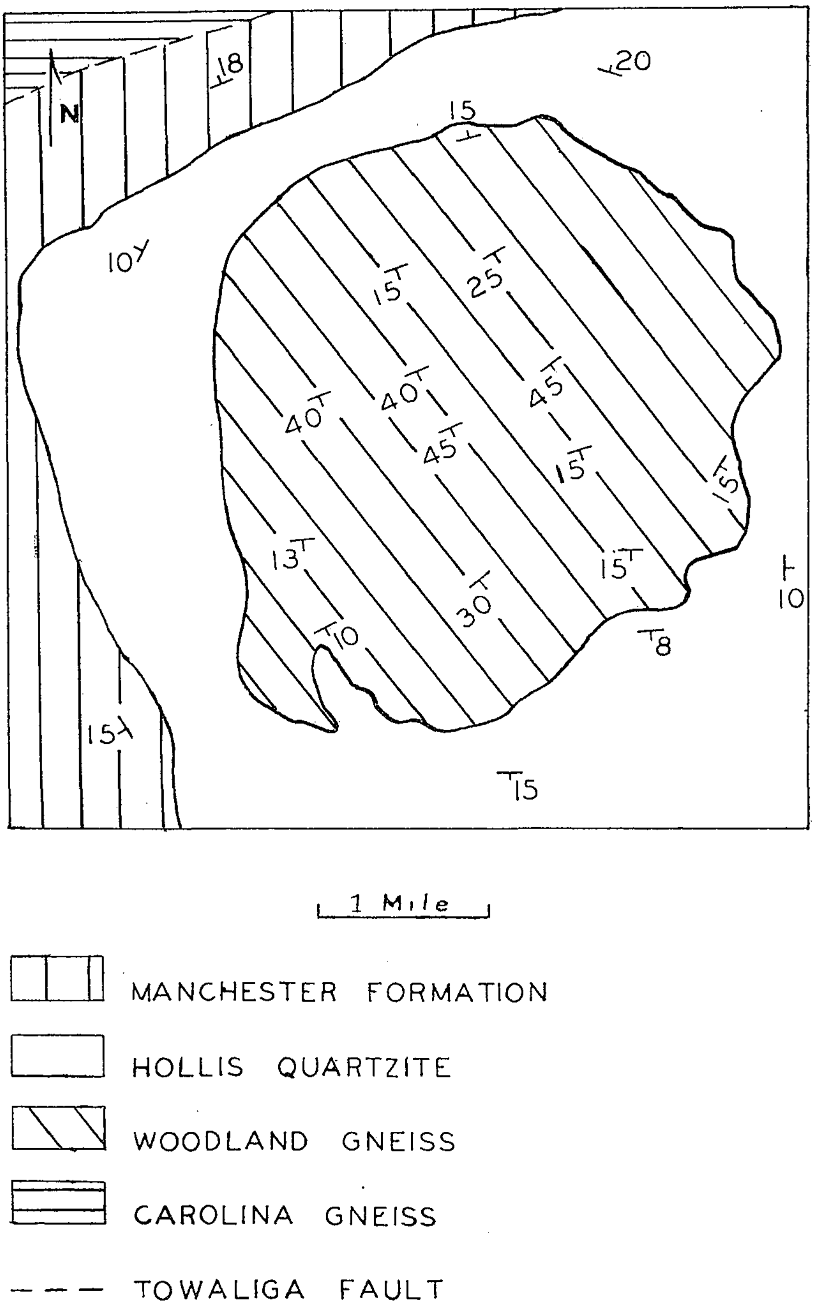

Plate I

Geologic map of The Cove and vicinity. Reproduced from Hewett and Crickmay (1937, Plate I).

Age and Correlation

The Woodland gneiss is the oldest formation in the Wacoochee belt. If the Hollis quartzite is pre-Cambrian, the Woodland gneiss is also pre-Cambrian. However, there is no positive evidence for the age of any of these rocks in this district.

The Woodland gneiss may be correlated with the gneiss underlying other quartzites in the Appalachian Piedmont province, but such a correlation is highly speculative.

HOLLIS QUARTZITE

Historical Review

The quartzites and schists of the Wacoochee belt in Georgia were grouped under the Pine Mountain formation by Galpin (1915, p. 74). Subsequently the principal quartzite of this terrane in Alabama was named the Hollis quartzite by Adams (1926, pp. 33-34) from exposures near Hollis, Alabama. Later Crickmay (1935, p. 32) correlated the basal quartzite of the Pine Mountain formation with the Hollis quartzite and applied the name Manchester formation to the metasediments overlying the Hollis quartzite. The Pine Mountain formation then became the Pine Mountain group and included the Hollis quartzite and Manchester formation.

The only comprehensive study of the Hollis quartzite was made by Hewett and Crickmay (1937, p. 27).

Areal Distribution

The Hollis quartzite extends from the Thomaston quadrangle southwestward through Georgia and Alabama to where it is covered by the sediments of the Atlantic Coastal Plain. Quartzites extend northeastward from the Thomaston quadrangle, but it is not clear whether these rocks are the Hollis quartzite or the quartzite member of the Manchester formation.

Within the Thomaston quadrangle Hollis quartzite underlies two separate areas. In the western part of the quadrangle it underlies an area of five square miles and along the northern margin it underlies four square miles. A cross-section through this formation is exposed along the road that goes over The Top on Pine Mountain. The best exposures, however, are on the north side of Tally Gap on the Flint River.

The calculated thickness of the Hollis quartzite on Oak Mountain is 800 feet and at The Top on Pine Mountain is 1100 feet.

Weathering Features

The Hollis quartzite resists weathering processes and forms ridges wherever it crops out. Nearly everywhere the scarp slope of the ridges is steeper than the dip slope. The lower contact of the quartzite is generally high on the scarp slope, and in some place along the west face of Pine Mountain the contact is within one hundred feet of the top of the ridge. The land surface on the dip slope is generally parallel to the bedding of the quartzite, and the upper contact of the quartzite is at the bottom of the slope in most places. The profiles in Plate II illustrate the adjustment of topography to the structure of the quartzite.

The thick-bedded zones outcrop commonly as ledges which can be traced great distances along the strike. The thin-bedded quartzite characteristically weathers to a very flexible itacolumite.

A thick deposit of rubble extends along the scarp slope of Pine Mountain as well as along the scarp slope of every ridge in the area that is held up by quartzite. These rubble deposits cover the contact in most places but do not interfere seriously with mapping.

In the immediate vicinity of the quartzite ridges there are stream gravels several feet thick which are composed of quartzite gravel and cobbles. Some of these gravels have been cemented with limonite to form conglomerate.

Petrography

In the Thomaston quadrangle the Hollis quartzite is composed of massive, pure quartzite, feldspathic and muscovitic quartzite, conglomeratic quartzite, and quartz schist.

Quartzite, pure variety. This rock is composed almost entirely of quartz; a small amount of microcline, muscovite, and rutile is present. Quartz and microcline are elongate parallel to the bedding. The muscovite flakes also lie parallel to the bedding. The boundaries of the quartz grains are sutured and interlocking, but those of microcline are smooth. The average grain size is 1 mm. A Rosiwal analysis of this rock is given in Table II (Spec. 1).

Table II

	1	2	3
Quartz	94%	34%	94%
Microcline	6	55	6
Muscovite	tr	6	
Biotite		5	
Others		tr[1])	

[1]) Zircon and ilmenite.
1 Hollis quartzite, pure variety. Tally Gap.
2 Hollis quartzite, impure variety. West bank of the Flint River one-half mile north of the junction with Mud Creek.
3 Quartzite member, Manchester formation. The gap 0.3 miles northwest of Atwater.

Quartzite, impure variety. This rock is composed of quartz, microcline, muscovite, biotite, ilmenite, and zircon. Its composition is quite like that of some varieties of Manchester schist. The fabric is granoblastic and the average grain size is 0.2 mm. A Rosiwal analysis of this rock is given in Table II (Spec.2).

Conglomeratic facies. This rock is composed of ellipsoidal quartz pebbles embedded in a matrix of ilmenite, rutile, muscovite, and zircon. The dimensions of the average quartz pebble are 20 mm. by 10 mm. by 5 mm. The average grain size of the minerals in the matrix is 0.2 mm.

Structure and Genesis

Most natural exposures of Hollis quartzite are of massive beds composed almost entirely of quartz. These beds are from one to five feet thick. Artificial exposures are generally of thin-bedded, impure quartzite which has a schistosity parallel to the bedding. A conglomeratic facies is exposed near the southwest side of Indian Grave Mountain. In some places feldspathic quartzites and quartz schists are interbedded with layers of pure quartzite. These layers of different composition are parallel to the contacts with the underlying Woodland gneiss and the overlying Manchester formation.

The several lithologic varieties that make up the Hollis quartzite are metasedimentary rocks derived from pure silica sandstones, argillaceous sandstones, arkoses, and conglomerates by regional metamorphism. Since all the metasediments of the Wacoochee belt within the Thomaston quadrangle are of the same metamorphic rank, there is no way to trace their metamorphic history.

Age and Correlation

In east-central Alabama the Hollis quartzite is associated with the Chewacla marble, a pure, massive dolomite which is lithologically similar to some of the Early Paleozoic dolomites of the Southern Appalachians. This association might be interpreted as indicating that the Hollis quartzite is Early Paleozoic in age. However, the Hollis quartzite is barren of fossils and at the present time cannot be correlated with any fossil-bearing formation. Therefore any suggestions as to age are without secure foundation.

MANCHESTER FORMATION

Introduction

The Manchester formation consists of three members. The lowest member is made up principally of mica schist, graphite schist, and kyanite-muscovite schist. It is called the lower schist member in this report. The middle member is a quartzite that is in every way similar to the Hollis quartzite. It is called the quartzite member in this report.

Stratigraphically above the quartzite member is a thick succession of metasediments, which are invaded by the Jeff Davis granite, a sill-like batholith. The base of the main mass of the intrusive is from three to eight thousand feet stratigraphically above the top of the quartzite member. Within this thick sequence, however, there are sills, pegmatites, and migmatites, which are genetically related to the Jeff Davis granite. As a practical expedient the rocks stratigraphically above the quartzite member and stratigraphically below the lowest sill satellitic to the Jeff Davis granite are mapped as the upper schist member.

Historical Review

The Manchester formation was named by Crickmay (1935, p. 32) from exposures near Manchester, Georgia. Hewett and Crickmay (1937, p. 29) refer to this unit as the Manchester schist. In view of the large amount of quartzite within the unit, however, the writer prefers to retain the original name Manchester formation.

Areal Distribution and Thickness

Within the Thomaston quadrangle the lower schist member crops out in four separate areas. It underlies twenty-eight square miles. Southeast of Oak Mountain the calculated thickness of this unit is 1200 feet. At Pasley Shoals it is about 1500 feet thick, and between The Top and Van Houten Mountain it is about 2500 feet thick. In the valley between Bull Trail Mountain and Indian Grave Mountain it is about 3000 feet. To the east the outcrop area thins rapidly due to faulting.

The quartzite member extends up the western side and across the northern part of the quadrangle as a continuous belt of hills and ridges. Within the quadrangle this unit underlies eleven square miles. The quartzite member is about 200 feet thick one-half mile north of Pleasant Hill. On Pine Woods Ridge it is about 800 feet thick, and north of Hickman Forks it is about 800 feet thick. On the east end of Bull Trail Mountain there is an excellent exposure of a complete section. Here the quartzite is about 500 feet thick.

The upper schist member forms a belt about one mile wide and seventeen miles long extending across the quadrangle. It underlies ten square miles within the quadrangle and averages 1500 feet in thickness.

Weathering Features

In comparison with the quartzites stratigraphically below and above, the lower schist member offers relatively little resistance to weathering. Fresh outcrops occur only along streams and on the sides of steep hills. Though artificial exposures in road cuts are weathered deeply for the most part, they generally still show the structure in all detail.

The quartzite member resists weathering and is a ridge-former just as is the Hollis quartzite.

Outcrops of the upper schist member are few; it is difficult to obtain even small fresh samples. However, in many road cuts the weathered material has retained the original structure of the rock.

Petrography

LOWER SCHIST MEMBER

The principal difference between this schist and the quartzite stratigraphically above and below is that the schist contains more biotite and muscovite. Some zones within the schist are richer in biotite; others are richer in kyanite. Plagioclase (An_{15} to An_{30}), microcline, rutile, garnet, zircon, and iron ore are generally present in every specimen. Apatite and tourmaline as well as chlorite occur in some.

Pin-wheel garnets were found in the lower schist member at Lawrence Mill and at the junction of Mud Creek and the Flint River. These structures indicate that the rock was undergoing a penetrative movement during progressive metamorphism.

Since there is such a great range in mineral composition in the rocks of this member, it is difficult to cite any particular one as typical. Two of the most common varieties are kyanite-muscovite schist and biotite schist.

Kyanite-muscovite schist. This rock is composed of quartz, muscovite, kyanite, and minor rutile. The fabric is foliated and crystalloblastic. The average grain size is 0.2 mm. A Rosiwal analysis of this rock is given in Table III (Spec. 1).

Biotite-schist. In hand specimen this rock appears to be intermediate between a schist and a gneiss.[1] In the same outcrop there are all gradations by increase in mica content to normal mica schist. This rock is composed principally of quartz, plagioclase (An_{35}), biotite, and garnet. Zircon, apatite, rutile, iron ore, and chlorite are also present. This rock contains a pin-wheel garnet whose spirally arranged inclusions indicate long rotation of the garnet during its growth. See Fig. 1. The average grain size of this rock is 0.5 mm. The

[1]According to British usage this rock would be termed a granulite. (Harker, 1932, p. 246.)

Table III

	1	2	3	4	5	6a	6b
Quartz	48	33	50	85	38	58	59
Plagioclase		35		3		2	14
Microcline					43	3	25
Biotite		19	22	10	19	30	2
Muscovite	42		28			7	
Garnet		11					
Kyanite	8						
Others	2[1])	2[2])		2[3])			

[1]) Mostly rutile, some biotite and ilmenite.
[2]) Muscovite, rutile, zircon, apatite, iron ore, and chlorite.
[3]) Muscovite, garnet, zircon, rutile, apatite, and magnetite.
1 Kyanite-muscovite schist, lower schist member, Manchester formation. West bank of Flint River 1.2 miles downstream from Pasley Shoals.
2 Garnet-biotite schist, lower schist member, Manchester formation. Lawrences Mill.
3 Mica schist, upper schist member, Manchester formation. The small valley 0.1 miles south of the Flint River between Spewrell Bluff and Owens Island.
4 Feldspathic mica schist, upper schist member, Manchester formation. 0.3 miles south of Hickman Forks.
5 Feldspathized schist, upper schist member, Manchester formation. Roadcut 0.5 miles S70°E of Atwater.
6 Injection gneiss, upper schist member, Manchester formation. Roadcut 0.7 miles south of Hickman Forks. 6a is a schist layer, and 6b is injected material.

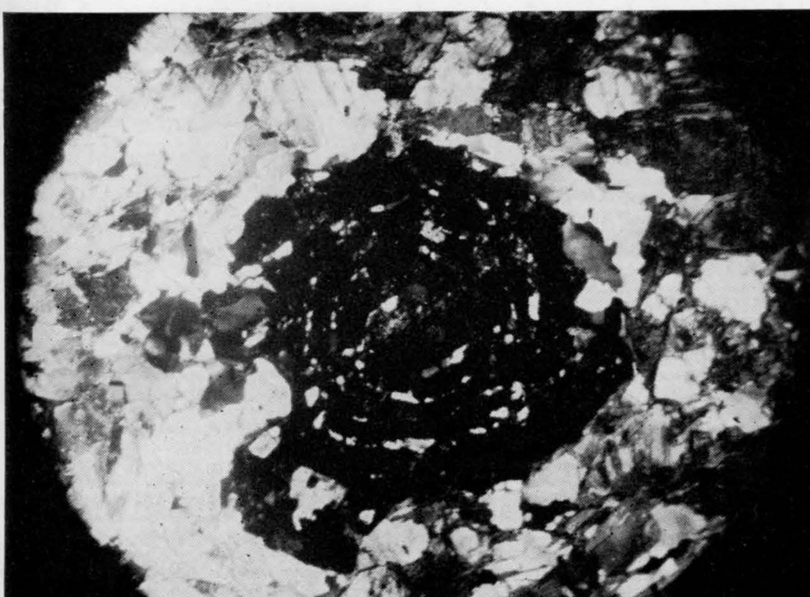

Fig. 1. Pin-wheel garnet from the lower schist member of the Manchester formation at Lawrence Mill. (20X, crossed nicols)

fabric is foliated and crystalloblastic. A Rosiwal analysis is given in Table III (Spec. 2).

QUARTZITE MEMBER

In hand specimen and in thin-section the quartzite member is just like the Hollis quartzite. The only possible difference between the two is that the Hollis quartzite may contain more impure zones than the quartzite member.

A typical specimen from this member contains quartz, microcline, and muscovite. The mineral grains are elongate parallel to the bedding. Quartz has highly sutured boundaries. Fig. 2 shows a quartz grain with a very irregular shape. Microcline has smooth, rounded edges, and muscovite is subhedral.

Fig. 3 shows the contrast between the smooth, rounded microcline grains and the very irregularly shaped quartz grains. The microcline grains are probably about the same size as they were when deposited; they have not recrystallized. The quartz grains have been recrystallized completely, and retain no trace of original sedimentary features. A Rosiwal analysis of this rock is given in Table II (Spec. 3).

That the quartz grains are flattened indicates that the rock has been deformed. A quartz grain like that shown in Fig. 2, however, could not have been subjected to appreciable postcrystalline deformation. Any effects of precrystalline deformation would have been obliterated by the recrystallization. Therefore the deformation must have been paracrystalline.

UPPER SCHIST MEMBER

This member is made up of mica schist, feldspathic mica schist, and muscovite-kyanite schist. Locally some injection gneiss is included.

Mica schist. A typical mica schist is composed principally of quartz, biotite, and muscovite. Small amounts of garnet, rutile, zircon, and ilmenite are also present. The fabric is crystalloblastic, fluidal, and the average grain size is 0.2 mm. A Rosiwal analysis of this rock is given in Table III (Spec. 3).

Feldspathic mica schist. A typical feldspathic mica schist

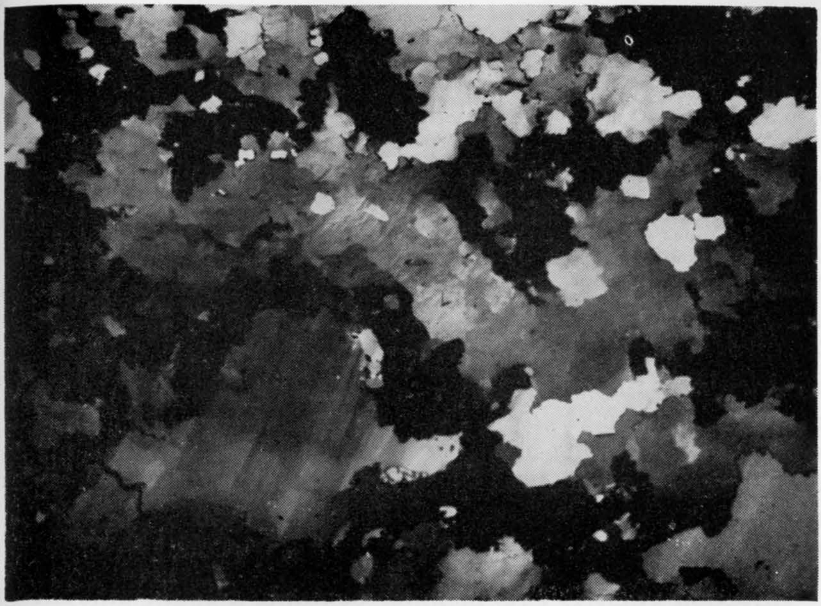

Fig. 2. Irregular quartz grain from the quartzite member of the Manchester formation at the gap 0.3 miles northwest of Atwater. (20X, crossed-nicols)

Fig. 3. Smooth grain of microcline in contrast to irregular grains of quartz. Same specimen as shown in Fig. 2. (50X, crossed-nicols)

is composed principally of quartz, biotite, and plagioclase (An_{20}). Accessory minerals include muscovite, garnet, zircon, rutile, apatite, and magnetite. The fabric is crystalloblastic, fluidal, and the average grain size is 0.3 mm. A Rosiwal analysis of this rock is given in Table III (Spec. 4).

Feldspathized schist. Some of the rocks of this member have the composition of a granite, but in hand specimen they have a strong foliation which suggests that they might be feldspathized (granitized) schist. Because of the limited outcrops, however, such an origin cannot be proved. These rocks might be small bodies of granite satellitic to the Jeff Davis granite. A typical specimen of this type is composed principally of microcline-microperthite, quartz, and biotite. Small amounts of plagioclase (An_{25}), garnet, zircon, and iron ore are present. The average grain size is 0.3 mm. A Rosiwal analysis of this rock is given in Table III (Spec. 5).

Injection gneiss. This member contains a small amount of layered rock which is interpreted as injection gneiss. This rock is probably related to the Jeff Davis granite in the same manner as the injection gneiss described under the schist-gneiss migmatite. One specimen is composed of well-defined, alternating dark and light layers. The dark layers are of a biotite schist which is composed principally of quartz, biotite, muscovite, microcline, and plagioclase (An_{20}). Also present are zircon, garnet, and ilmenite. The light layers are composed principally of quartz, microcline, and plagioclase (An_{20}). There are also small amounts of biotite and muscovite. The average grain size for both layers is 0.5 mm. Rosiwal analyses for both dark and light layers are given in Table III (Spec. 6a and 6b).

STRUCTURE

All the members of the Manchester formation are characterized by the presence of layers of different composition which are parallel to the internal schistosity. Both the layering and the schistosity are in turn parallel to the contact with the Hollis quartzite and to the contacts between the members themselves. The layers of different composition are regarded as original sedimentary bedding.

Where the road crosses Basin Creek about one mile northeast of Robert Green Hill the quartzite exhibits a structure which is apparently cross-bedding. In Fig. 4 the cross-bedding dips uniformly. In Fig. 5, however, it is buckled and has an S-shape, indicating that the rock has been deformed.

The broader aspects of the structure of the Manchester formation are discussed in the chapter on Structure.

Genesis and Metamorphism

The quartzite and schist of the Manchester formation have developed from sandstone and shale by regional metamorphism. Since these rocks are of the same metamorphic rank everywhere observed, the metamorphic history could not be worked out.

The injection gneiss (Spec. 6) described under the petrology of the upper schist member indicates that the Manchester formation had reached its present rank of metamorphism before the Jeff Davis granite was emplaced. The foliation of the schist layers of this specimen reflect recrystallization under a directed pressure; the granitic layers show little indication of having been affected by kinetic metamorphism. Therefore the schist must have acquired its foliation before the granitic layers were injected. Also the rocks of the Manchester formation do not show an increase in rank of metamorphism in proximity to the Jeff Davis granite. They are of the same rank everywhere in the quadrangle.

That kinetic metamorphism was a factor in the development of these rocks is demonstrated by the pin-wheel garnets in the lower schist member and the elongate quartz grains in the quartzite member. However, kyanite and garnet reflect a relatively high temperature of formation. An environment of this kind is best explained as an effect of geothermal gradient. Therefore the development of the rocks of the Manchester formation is believed to have been effected principally by geothermal metamorphism in conjunction with kinetic metamorphism.

Age and Correlation

The Manchester formation is younger than the Hollis quartzite and older than the Jeff Davis granite. However,

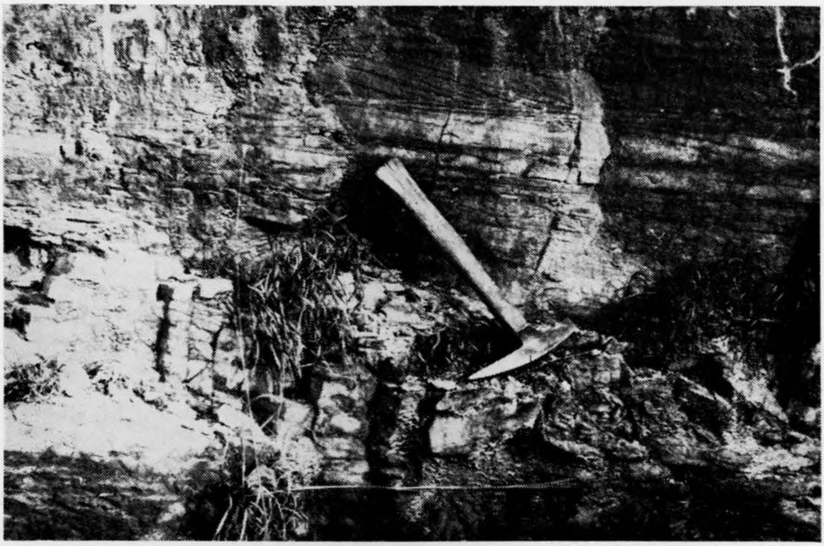

Fig. 4. Cross-bedding in the quartzite member of the Manchester formation. This locality is one mile northeast of Robert Green Hill in a road-cut where the road crosses Basin Creek.

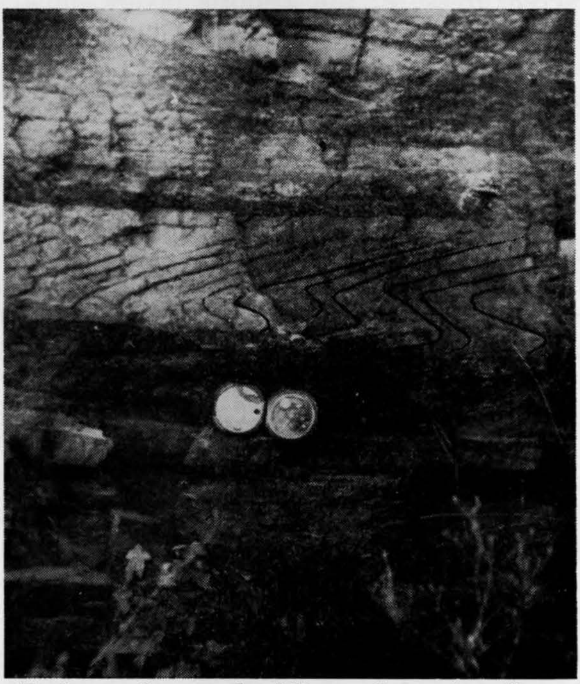

Fig. 5. Deformed cross-bedding. Same locality of Fig. 4.

there is no positive evidence concerning the age of any of these rocks.

A. S. Furcron (personal communication) calls attention to many other occurrences of quartzite in the Appalachian Piedmont east of the Brevard thrust. Some of them are overlaid by mica schist, and he believes that these rocks apparently lie unconformably on older basement rock. On the basis of reconnaissance he correlates these quartzites and schists with the Hollis quartzite and Manchester schist, and regards them as Late Precambrian remnants lying on an earlier Precambrian basement.

JEFF DAVIS GRANITE

A batholith of garnetiferous biotite granite underlies a great part of the central and eastern portions of the Thomaston quadrangle. The name Jeff Davis granite is here proposed for this lithologic unit from the instructive exposures near the Jeff Davis School, which is five miles northwest of Thomaston.

Historical Review

This granite mass has not been described previously as a separate unit. Crickmay (1935, p. 33) apparently recognized its existence when he wrote that the Pine Mountain group "is intruded by igneous rocks, mainly biotite augen gneiss and garnet-hypersthene granite." On the State Geologic Map (1935) the area underlain by both the Jeff Davis granite and the schist-gneiss migmatite surrounding it are denoted as augen gneiss.

Areal Distribution

The main body of the Jeff Davis granite underlies an area of fifty-seven square miles within the Thomaston quadrangle. Large sills of the same kind of granite occur in the area to the north and south of the main mass. Though the relationship of these sills to the main mass cannot be proved positively, similarity in lithology and close relationship in space indicate strongly that both the sills and the main mass belong to the same episode of intrusion.

Weathering Features

The Jeff Davis granite is very susceptible to weathering, and as a result good exposures occur only along streams. Along Ten Mile Creek and Potato Creek are rapids and falls which have been sites of many grist mills. These places afford broad, clean exposures which stand in great contrast to the more or less deeply weathered areas between the streams.

The question often arises as to whether an outcrop along a stream is typical of a geologic unit, most of which is deeply weathered, or whether it outcrops because it is different from the rest of the unit. If the controlling factor is a difference in the mineralogy of the rock, the geologist may get an erroneous impression of the nature of a unit. This problem is of major importance in regard to the Jeff Davis granite. Most of the specimens, from which defining characteristics were obtained, came from outcrops along streams. These outcrops are separated by large areas of no exposures.

However, no rock of this unit has a mineral composition that should give it a greater resistance to weathering. In addition, outcropping rock does not show persistence along zones parallel to the foliation. Large outcrops commonly have a vertical long dimension transverse to the foliation. Therefore it seems most probable that the resistant areas are not due to mineral composition but due to some structure. Wide spacing of joints may be the controlling factor.

Petrography

Of the eighty-five specimens from this batholith that were studied in thin-section, fifty-five have the composition of granite, twenty-eight have the composition of quartz monzonite and granodiorite and two have the composition of quartz diorite. This classification is based on the ratio of microcline to plagioclase. However, there is no relationship in space of rocks with one particular composition. Also the variation in the calcium content of the plagioclase and the variation in the total amount of mafic minerals present do not correspond to the variation in ratio of microcline to plagioclase. This absence of relationship in space and of systematic variation in mineralogical characteristics indicates that the mineral ratios are fortuitous within certain limits. For example, two thin-sections were made from one specimen. One had the ratio of feldspars of a granite, and the other had that of a quartz monzonite. Some of the variations may represent facies; others may be the result of separate intrusions.

The appearance of the Jeff Davis granite as seen in field exposure shows a rather wide variation. Around Jeff Davis School the rock has a moderately developed foliation. Biotite and garnet are concentrated in disc-like patches that give the rock a blotchy appearance. At Paynes Mill biotite and garnet are concentrated in continuous folia which can be traced for several feet. Rocks with continuous folia are much more common than those with the blotchy appearance. On Potato Creek a few hundred feet south of U. S. Route 74 the rock is more nearly isotropic, and in a few places there is no orientation of the mafic minerals at all. This is the only locality where foliation was not observed in the Jeff Davis granite.

In all specimens examined the fabric is allotriomorphic; biotite alone shows crystal faces. In most thin sections the biotite has a strong orientation. The grain size is about 0.5 mm. In a few rocks, however, grains of feldspar are as much as 5 mm. or more in width.

The composition of the plagioclase ranges from An_{25} to An_{40}, but in most specimens it is between An_{30} and An_{35}. It is absent in many of the granites except as exsolution lamellae in microcline-micropherthite.

The potassium feldspar is microcline. Grid twinning is well developed. Most of the grains are the same size as the quartz grains in the rock and are not perthitic. However, there are generally a few larger grains present in every thin-section which are perthitic, and in some specimens all the microcline is perthitic.

Quartz contains no significant amount of inclusions. Most grains show strain.

Biotite generally has the pleochroic formula: X = light brownish yellow, Y = Z = dark gray green to opaque. In some specimens, however, X = pale brown, and Y = Z = red brown.

Garnet occurs generally as individual anhedral grains. All garnets studied have a relatively uniform composition. The almandite content ranges from 50% to 70%, the pyrope content from 10% to 30%, and other garnet end members from 10% to 30%.

Accessory minerals include green hornblende, augite, sphene, zircon, allanite, apatite, rutile, magnetite, and ilmenite.

Rosiwal analyses of four typical specimens of the Jeff Davis granite are given in Table IV.

Xenoliths occur in the Jeff Davis granite on Ten Mile Creek just west of Jeff Davis School. In hand specimen these xenoliths look like biotite schist of the Manchester formation. However, the minerals present are the same as those in the granite, and the only difference between the two rocks is that the percentage of biotite is much higher in the xenoliths. The schist may have been feldspathized (granitized) before or after its inclusion within the granite.

Though observations are limited, there is an apparent relationship in space between the presence of xenoliths and the blotchy appearance of the granite. Also the blotchy granite generally has a higher content of mafic minerals. Therefore

Table IV

	1	2	3	4		5
Microcline	47%	39%	74%	52%	Plagioclase	21%
Plagioclase		7			Quartz	41
Quartz	37	47	20	41	Diopsidic	
Biotite	16	5	4	2	pyroxene	12
Garnet		2	2	5	Garnet	11
Others	tr[1])	tr[2])	tr[3])	tr[4])	Vesuvianite	8
					Scapolite	7

[1]) Garnet, zircon, allanite, and apatite.
[2]) Zircon, pyrite, magnetite, and sericite.
[3]) Apatite, zircon, hornblende, and magnetite.
[4]) Rutile, zircon, sphene, and magnetite.
1 Jeff Davis granite. Ten Mile Creek 0.25 miles west of Jeff Davis School.
2 Jeff Davis granite. Potato Creek 0.1 miles south of State Route 74.
3 Jeff Davis granite. Potato Creek 0.1 miles south of State Route 36.
4 Jeff Davis granite. Roadcut three miles southeast of Thomaston and 0.5 miles northwest of road junction 658.
5 Contact metamorphic rock. Road 0.5 miles south of Dog Crossing.

it is possible that the blotchy granite is a facies that has been produced by enrichment in mafic mineral content through assimilation of biotite-rich xenoliths.

Marginal Effects

In the northeast corner of the quadrangle a hornfels occurs at the contact between the Jeff Davis granite and metasediments of the schist-gneiss migmatite. This contact-metamorphic rock is composed of quartz, bytownite (An_{70}), garnet, vesuvianite, diopsidic pyroxene, scapolite, sphene, and apatite. A Rosiwal analysis of this rock is given in Table IV (Spec. 5).

The unusual mineral composition of this hornfels indicates that it was originally a calcareous, siliceous sediment. However, there is no evidence concerning its mineral composition at the time of intrusion of the granite.

Marginal to the Jeff Davis granite is a broad belt of mixed rocks. These rocks are composed of interlayered schists, gneisses, and gneissic granites. Injection gneiss and pegmatites are also present. This belt of mixed rocks is regarded as having been formed principally by intrusion of sills satellitic to the main mass of the Jeff Davis granite into schist of the upper schist member of the Manchester formation. Feldspathization of part of the interlayered schist was effected by emanations from the sills and from the main mass.

These mixed rocks form a mappable unit and in this report are given the status of a formation, the schist-gneiss migatite.

Structure, Genesis, and Mode of Emplacement

The Jeff Davis granite is characterized generally by a weak to moderate foliation. Throughout that portion of the mass within the Thomaston quadrangle the foliation has an east-west to N45°E strike and a dip of 30° to 60° to the south. The foliation is imparted to the rock by an orientation of the biotite flakes and by a greater concentration of biotite and garnet in the alternate layers. Within the foliation there is commonly a horizontal lineation which is produced by linear concentrations of biotite and garnet.

Xenoliths occur in the granite along Ten Mile Creek just west of Jeff Davis School. The xenoliths are generally angular, blocky, and have no reaction rims. They show no orientation to the foliation of the granite, nor do they show any mutual orientation.

If the foliation and lineation had been produced in the solid state, the xenoliths would be deformed. Since the xenoliths are blocky, angular, and generally undeformed, the structure in the granite must have developed in the liquid state, that is, in a magma. The presence of a lineation indicates further that the structure developed from flow of the magma.

If the lineation is parallel to the "b" fabric axis, flow was upward; if parallel to the "a" fabric axis, flow was horizontal. The chances of so many sills all having an exactly horizontal flow is not likely. If movement was generally lateral, one would expect to find some with a diagonal flow. If flow were upward, no diagonal flow would necessarily be expected. Therefore flow was probably upward and the lineation is parallel to the "b" fabric axis.

That the contacts of the granite are parallel to the foliation in the wall rock in some places and apparently crosscutting in others indicates that the same relationship holds in vertical cross-section. However, the crosscutting contacts may be due to faulting. In this case, the intrusive contacts are generally conformable, and the batholith is sill-like in structure.

The xenoliths demonstrate some stoping, but they are few in number and small in size. The presence of almandite indicates some assimilation. However, the general sill-like structure of the batholith indicates that the principal mode of emplacement probably was forceful injection.

Age and Correlation

The Jeff Davis granite is younger than the upper schist member of the Manchester formation and older than the charnockite series. It is also older than the faulting in the vicinity of Brooks Mountain. There is no evidence on the exact geologic age except that it is older than the Upper Cretaceous Tuscaloosa formation.

The writer knows of no other igneous rocks with which the Jeff Davis granite can be correlated.

SCHIST-GNEISS MIGMATITE

Introduction

A thick sequence of metasediments overlies the quartzite member of the Manchester formation, and intrusive into these metasediments is the batholith of Jeff Davis granite. Granite sills satellitic to the batholith are interlayered with the metasediments stratigraphically above (south) and below (north) of the main mass. These two belts of mixed rocks are a mappable unit and in this report are denoted the schist-gneiss migmatite.

Historical Review

The schist-gneiss migmatite and the Jeff Davis granite are not differentiated on the State Geologic Map; both are designated as "Augen gneiss." However, in the Warm Springs quadrangle, Hewett and Crickmay (1937, Plate 3) mapped this migmatite as granitized Manchester formation.

Areal Distribution

The horizon at the base of the first granite sill stratigraphically above the quartzite member of the Manchester formation was chosen as the base of the lower (northern) belt. The contact with the main mass of the Jeff Davis granite marks the top of this belt. The base of the upper (southern) belt is marked by its contact with the main mass of the Jeff Davis granite. Within the Thomaston quadrangle this belt is cut by the Goat Rock fault; therefore its extent stratigraphically upward is not known.

Within the Thomaston quadrangle the lower (northern) belt underlies seventeen square miles and the upper (southern) belt underlies forty square miles. The extent of these rocks outside the quadrangle to the northeast and southwest is not known.

Weathering Features

In this region feldspathic rocks show little resistance to weathering. Since all the rocks of this unit are characterized by a large percentage of feldspar, outcrops are few. However, most of the fresh outcrops are of gneiss. Deeply weathered artificial cuts in schist terranes generally reveal much information. The muscovite in the schist resists weathering and shows clearly the original structure, whereas the gneiss commonly weathers to a structureless mass of clay.

Petrography

The two belts of schist-gneiss migmatite have the same general characteristics. They are composed principally of muscovite-kyanite schists, kyanite gneisses, and biotite granites. These varieties are present in about equal proportions. Kyanite-sillimanite gneisses, injection gneisses, and pegmatites are also common.

Biotite granite. A typical granite from this unit is composed of microcline-microperthite, quartz, plagioclase (An_{25}), biotite, and garnet. The fabric is allotriomorphic and the average grain size is 0.5 mm. This rock is similar in every way to typical varieties of the Jeff Davis granite. A Rosiwal analysis of this rock is given in Table V (Spec. 1).

Kyanite gneiss. Nearly every kyanite gneiss examined has the mineral composition of a normal granite except for the presence of kyanite. The amount present generally ranges from one to three percent, though a few specimens had only a few grains in the whole slide. A typical specimen is composed of microcline-microperthite, quartz, kyanite, biotite, and garnet. The grains are generally equant, anhedral, and average 0.2 mm. in width. A Rosiwal analysis of this rock is given in Table V (Spec. 2).

Kyanite-sillimanite gneiss. In addition to kyanite, sillimanite is present in several specimens examined. A typical kyanite-sillimanite gneiss contains microcline-microperthite, quartz, sillimanite, kyanite, biotite, and garnet. The average grain size is 0.2 mm. A Rosiwal analysis is given in Table V (Spec. 3).

Injection gneiss. At several localities within this terrane the rock appears to be injection gneiss. In one specimen layers of biotite schist are separated by stringers of plagioclase (An_{15}) and quartz. This rock is shown diagrammatically in Fig. 6.

Table V

	1	2	3	4
Microcline	54%	50%	52%	31%
Quartz	37	46	45	33
Biotite	9			18
Kyanite		4	1	
Sillimanite			2	
Garnet				15
Others	tr[1])	tr[2])	tr[3])	tr[4])

[1]) Plagioclase (An_{25}), garnet, apatite, and zircon.
[2]) Rutile, garnet, and biotite.
[3]) Garnet and biotite.
[4]) Plagioclase (An_{30}), apatite, sphene, zircon, and allanite.

1 Biotite granite. B. M. 548 on Talbotton Road about five miles south of Thomaston.
2 Kyanite gneiss. South bank of Potato Creek 0.5 miles N45°E of St. Paul Church.
3 Kyanite-sillimanite gneiss. Creek 0.7 miles N10°E of Mt. Airy School.
4 Injection gneiss. Yellow Jacket Shoals on the Flint River.

Another rock that can be interpreted as an injection gneiss crops out in broad exposures at Yellow Jacket Shoals on the Flint River. In the outcrop, the rock is characterized by a black and white striped appearance. The light layers are generally 3 mm. to 10 mm. thick and the dark layers 1 mm. to 3 mm. thick. In thin section the banding is well-defined as shown in Fig. 7. The dark layers are composed of biotite, garnet, apatite, sphene, zircon, allanite, and quartz. The light layers are composed of microcline, quartz, and plagioclase (An_{30}). The average grain size is 0.3 mm. A Rosiwal analysis of this rock is given in Table V (Spec. 4).

Muscovite-kyanite schist. The belts of schist within this unit are deeply weathered, and no fresh specimens were obtained. In artificial exposures weathered schist still retains its original structure. Muscovite remains fresh, and kyanite weathers to a characteristic white aggregate which commonly retains traces of the kyanite cleavage. Quartz and weathered feldspar are also present. Muscovite is apparently the predominant varietal mineral in the lower (northern) belt and kyanite the predominant varietal mineral in the upper (southern) belt. However, exposures of these varieties are too few to warrant final conclusions as to distribution.

Quartz-anorthite granulite. Small lenses of dark, fine-grained granulite occur at several places within the schist-

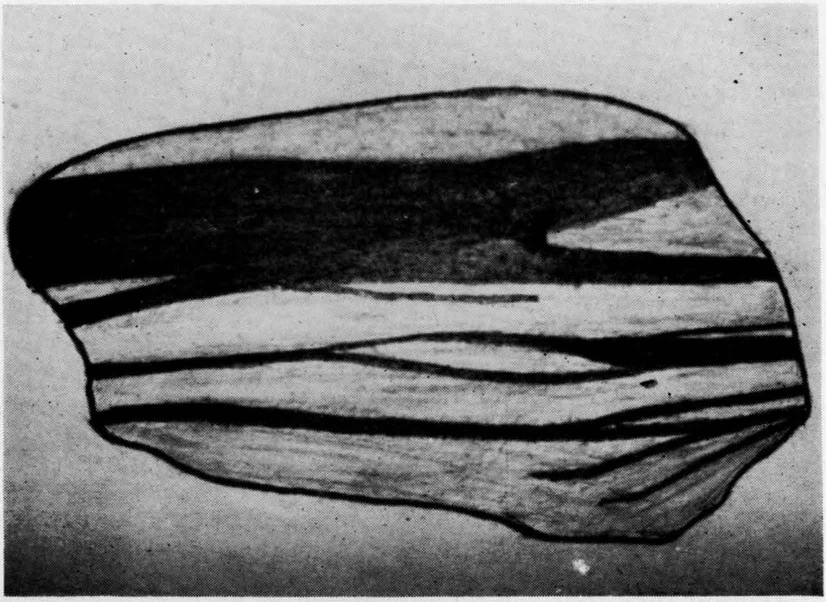

Fig. 6. Diagrammatic representation of injection gneiss. Layers of biotite schist (dark) are separated by stringers of plagioclase (An_{15}) and quartz (light). (1X)

Fig. 7. Injection gneiss from Yellow Jacket Shoals showing well-defined layering. (20X, plane polarized light)

gneiss migmatite. A typical specimen from one of these lenses is composed of quartz, anorthite (An_{90}), diopsidic clinopyroxene, and garnet. Minor amounts of ilmenite and sphene are present. The fabric is granoblastic and the average grain size is 0.5 mm. This rock, like the hornfels (Table IV, Spec. 5) described in conjunction with the Jeff Davis granite, was probably derived from a calcareous, siliceous lens of sedimentary origin. Similar rocks in Finland are interpreted by Eskola (1933, p. 19) as metamorphic derivatives of calcareous concretions.

Pegmatites. Most of the pegmatites are so deeply weathered that no fresh material can be obtained. Several of the larger pegmatites, however, have been mined for mica, and the dumps around these mines give some idea as to the mineral composition. Furcron and Teague (1943, pp. 19-48) made a comprehensive study of these pegmatites and have published detailed descriptions of each prospect. Their study revealed that most of the pegmatites have at least two zones, an outer zone of microcline and muscovite and inner cores of quartz. The observations of the writer are in accord with this interpretation.

Besides microcline, muscovite, and quartz, generally biotite and albite are present. Smaller amounts of tourmaline, beryl, apatite and garnet are not uncommon.

Structure and Genesis

Biotite granite. The granite within this unit is generally foliated and the foliation is parallel to the schistosity of the enclosing schists. In those places where contacts were observed, the plane of contact is parallel to the foliation of both granite and schist. Therefore these masses are probably sills.

This granite is petrographically like the Jeff Davis granite and occurs marginal to it in masses which are probably sills. Therefore the best interpretation is that they are granite sills satellitic to the main mass of the Jeff Davis granite.

Kyanite gneiss. Except for the presence of kyanite, the kyanite gneisses have the composition of granite. There is a contact between a kyanite gneiss and a muscovite-kyanite schist in a road-cut on U. S. Route 19 one mile south of Indian Grave Mountain. Here the gneiss overlies the schist and the contact is sharp.

The kyanite gneisses may have originated by one or more of these processes:

1. Granitization of aluminous sediments to form kyanite gneiss.

2. Introduction of kyanite into granite sills by hydrothermal processes.

3. Regional metamorphism of argillaceous arkoses to form kyanite gneiss.

4. Assimilation of kyanite by granite sills satellitic to the main mass of the Jeff Davis granite to form kyanite granite.

Any metamorphic process that could change schist into gneiss should leave behind at least a small intermediate zone between the beginning and end products. Therefore the sharp contact between kyanite gneiss and muscovite-kyanite schist casts strong doubt on the possibility that the kyanite gneiss could be a product of granitization.

Massive kyanite of hydrothermal origin has been described in Georgia by Prindle (1935, p. 37). It is believed that by hydrothermal action kyanite material migrated from schists to form veins of massive kyanite. Associated tourmaline and occurrence of the kyanite in veins are the principal evidence for hydrothermal origin. The kyanite gneisses of the Thomaston quadrangle contain no tourmaline; the kyanite is generally disseminated and is not in veins. Therefore the kyanite is not believed to be of hydrothermal origin.

The interpretation that the kyanite gneiss is a metamorphosed argillaceous arkose calls for unusual but not impossible conditions of original sedimentation. There must have been several abrupt changes from deposition of argillaceous material to deposition of an arkose with a rather constant ratio of quartz, microcline, and plagioclase. There is no positive evidence for or against this interpretation, however.

That the kyanite gneisses have generally the composition of granite indicates that they are kyanite granites and that the kyanite was derived from assimilation of kyanite schist. Since the amount of kyanite in these gneisses is small, the amount of assimilated material would not have been great enough to alter appreciably the general composition of the assimilating magma. However, there is no positive evidence for or against this interpretation.

Kyanite-sillimanite gneiss. This variety differs from the kyanite gneiss only by the presence of sillimanite. The problem of origin is the same for both varieties. However, it is not clear just why kyanite and sillimanite occur in the same rock. This is contrary to the phase rule. There is no indication that the sillimanite has developed from kyanite. Both minerals occur as discrete grains. One possibility is that the rock was originally a kyanite-biotite gneiss and that biotite was converted into sillimanite by a subsequent metamorphism. However, there is no evidence that this process has been effective in these rocks. Another possibility is that first kyanite alone was present in the gneiss and that later sillimanite was added by hydrothermal action. Still another possibility is that sillimanite developed from one type of clay mineral and kyanite from another. However, the apparent anomalous occurrence of these two minerals in the same rock may reflect a complex history of metamorphism which, because of its complexity, cannot be traced.

Injection gneiss. These gneisses are interpreted as having been formed by lit-par-lit injection of granitic material along the foliation planes of biotite schists. The injected material may have been in the form of a highly fluid magma in some places and in the form of hydrothermal solutions in others.

Muscovite-kyanite schist. These schists are medium-rank metamorphic rocks that were derived from aluminous sediments by regional metamorphism. They are of the same metamorphic rank as the rocks of the Manchester formation. Since there is no change in metamorphic facies within these rocks, there is no way to trace the development of metamorphism.

Pegmatites. A great number of pegmatites occur within the schist-gneiss migmatite, and a few occur within the Jeff Davis granite. Some of the pegmatites are conformable to the foliation of the enclosing rocks, but most of them are cross-cutting. Cameron et al (1949, p. 5) cite this area as an example of pegmatites that are not related to any known igneous mass. However, these pegmatites are localized in space around the batholith of Jeff Davis granite and are therefore considered to be genetically related to this body.

Age and Correlation

The rocks of this unit are of two ages. The muscovite-kyanite schists are the stratigraphic upward continuation of the upper schist member of the Manchester formation, and all age and correlation data are the same as those given for the Manchester formation.

If the kyanite gneisses and kyanite-sillimanite gneisses are contaminated granites, they are to be regarded as the same age as the Jeff Davis granite.

The biotite granite, the pegmatites, and the injection gneisses are regarded as related to the Jeff Davis granite and therefore of the same age. The Jeff Davis granite is not correlated with any other intrusive mass.

CHARNOCKITE SERIES

Introduction

Within the Thomaston quadrangle are three mappable bodies of plutonic igneous rocks that belong to the charnockite series. These rocks are intrusive into the Jeff Davis granite and schist-gneiss migmatite. Petrographically they form a consanguineous series from hypersthene gabbro to hypersthene granite and appear to be closely similar to charnockite series of other parts of the world.

Historical Review

The body of these rocks in the southwest portion of the quadrangle extends on into the Warm Springs quadrangle where it was designated as Cunningham granite by Hewett and Crickmay (1937, Plate III). Within the Thomaston quadrangle, however, this mass is made up chiefly of quartz monzonites, granodiorites, and gabbros of the charnockite series.

Therefore the name Cunningham granite is not used in this report.

On the State Geologic Map the presence of two small bodies of garnet-pyroxene granite near Thomaston are shown. These areas were mapped during rapid reconnaissance work, however, and do not correspond to the areal distribution determined by this more detailed study.

Areal Distribution

The main mass of the charnockitic rocks underlies an area of nine square miles. It extends from Thomaston eastward into the next quadrangle. The outline of this body is lobate and cross-cutting in relation to the foliation of the Jeff Davis granite which it intrudes.

South of the main mass is a smaller body which is intrusive into the Jeff Davis granite and the schist-gneiss migmatite. This mass underlies seven-tenths square miles within the Thomaston quadrangle.

North and west of Silvertown there are many outcrops of these charnockitic rocks. The exposures are separated from each other by Jeff Davis granite and are too small to be considered individually as mappable units. Their connection with the main mass is at depth or is obscured by weathering.

In the southwest portion of the quadrangle charnockitic rocks and related rocks underlie eight square miles. These rocks are intrusive into schist-gneiss migmatite and Jeff Davis granite.

Similarity in hand specimen of the several members of the charnockite series renders mapping in the field of each variety difficult. The extensive soil-covered areas between outcrops add to this difficulty. Therefore little can be said concerning the areal distribution of the several members constituting the charnockite series. It seems clear, however, that there are no large bodies of any one member. Charnockite, hypersthene-quartz monzonite and hypersthene granodiorite occur in about equal proportions, whereas norite and hypersthene gabbro are quantitatively less important.

No actual contact could be found in the field between the charnockitic rocks and the surrounding terranes. However, the intrusive nature of the charnockitic rocks can be demonstrated by indirect evidence.

First, the composition of the several members of the charnockite series indicates quite clearly that these rocks are igneous. This subject is discussed in detail in the section on Genesis.

Second, the petrographic contrast between the charnockitic rocks and the invaded rocks is pronounced both in the field and in thin section. Exposures of charnockitic rocks occur within a few feet of exposures of normal granite. Yet, no rock was found that could be called transitional between the two. Outcrops of charnockitic rocks were also found in close proximity to outcrops of kyanite gneiss; no rocks transitional between these two were found.

Third, the outline of the areas underlain by the charnockitic rocks is irregular, lobate, and generally cross-cutting to the N70°E trend of the foliation of the surrounding Jeff Davis granite and schist-gneiss migmatite.

On the basis of these three lines of evidence the charnockitic rocks are believed to be intrusive into the Jeff Davis granite and schist-gneiss migmatite.

Weathering Features

The weathering features of the charnockitic rocks are characteristic and are aids to field mapping. Weathering is extremely deep and fresh rock as a rule is present only along streams. Even there, however, outcrops are far apart.

Most outcrops and residual boulders of the charnockitic rocks exhibit well developed spheroidal weathering. The exfoliation shells range from one to two centimeters in thickness. If the core of one of these exfoliation boulders is fresh, it is generally uniformly fresh throughout. Also, the innermost shell next to the core is uniformly weathered. Apparently each shell weathers as a unit and not gradually from the outside inward. Fig's. 8 and 9 show characteristic exfoliation boulders.

The most prominent characteristics of fresh rock of the

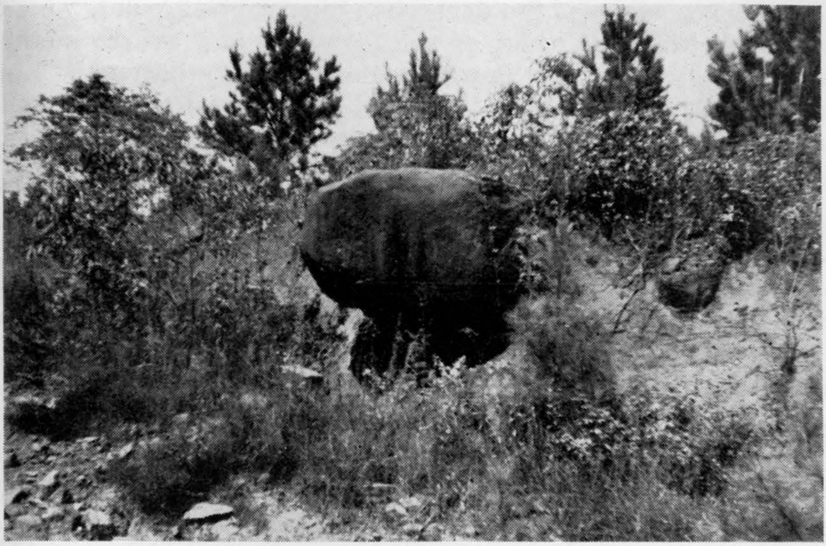

Fig. 8. Spheroidal weathering characteristic of the rocks of the charnockite series. This boulder of charnockite, probably from a dike, is north of the main mass of charnockite on an east-west road about one-half mile northwest of Paynes Mill.

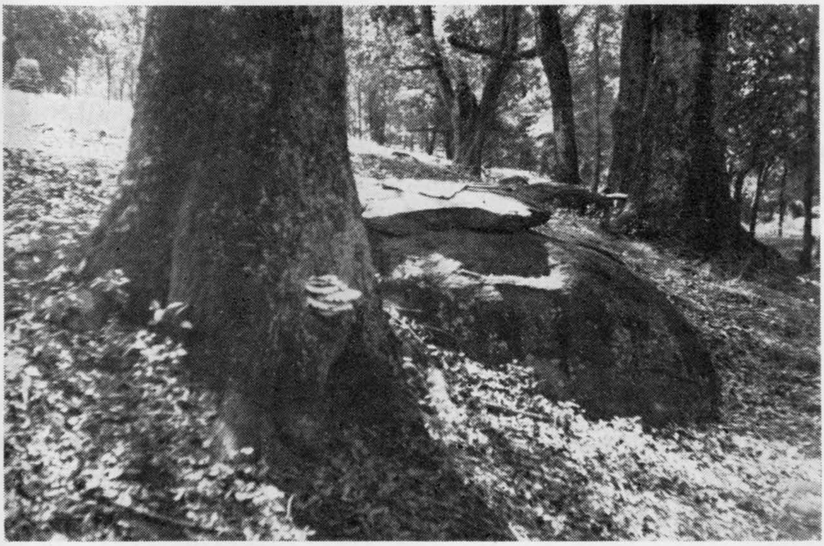

Fig. 9. Spheroidal weathering of charnockitic rock in the Public Park of Thomaston.

charnockite series is the dark blue, almost black color, which is due to the dark color of the feldspars and quartz in the rock. On weathering, however, the feldspars become white and render the rock much lighter in color. This lighter colored material is quite similar to weathered Jeff Davis granite.

The studies of Watson (1901, p. 106) on granites of Georgia have shown that the color of soil is not a direct function of composition of the rock from which the soil is derived. Generally, however, soil derived from the charnockitic rocks is dark red, darker than that derived from the contiguous Jeff Davis granite and schist-gneiss migmatite.

Petrography

Within the Thomaston quadrangle the charnockite series is represented by all members from hypersthene gabbro to charnockite; only the ultramafic members are absent.

The most characteristic feature of the charnockite series is the invariable presence of hypersthene in each member of the series. The hypersthene ranges in composition from Fs_{25} to Fs_{50}. All the potassium feldspar is microcline-microperthite, and the volumetric ratio of ex-solved plagioclase (An_{25}) to the host of microcline is as a rule unusually high. The plagioclase ranges from An_{75} in the hypersthene gabbro to An_{30} in the charnockite. Quartz occurs in those rocks more silicic than norite, and zircon has about the same range. There is some biotite in most specimens. Garnet occurs in all members of the series and augite and hornblende in some. Accessory minerals include apatite and ilmenite. Sphene does not occur in any member of the series.

In the eastern part of the quadrangle the charnockitic rocks are equigranular; in the western part most but not all are porphyritic. Both types are allotriomorphic. Biotite alone exhibits crystal faces.

Charnockite. Charnockite is a hypersthene granite which is dark bluish-gray in hand specimen. The charnockites of this area have an allotriomorphic fabrics, and the average grain size is 0.5 to 2 mm.

The plagioclase in all specimens studied is about An_{30}. Most grains show albite twinning. This twinning, however, is developed in only part of some grains and is entirely lacking in others. Zoning is generally present and the outer zones are more sodic. In a few grains the outermost zone is composed of albite (An_{10}). This zoned plagioclase is not composed of sharply defined shells each of uniform composition. Instead the composition changes gradually, so that as the stage is rotated under crossed nicols the extinction shadow moves as a circle in and out at an even rate.

The potassium feldspar in all specimens examined is microcline-microperthite. In most grains grid-twinning is poorly developed or absent. In a few grains, however, it is moderately developed. The plagioclase (An_{25}) exsolution lamellae occur as blebs and make up as much as 60 percent by volume of some grains of microperthite. The number of blebs per unit cross-sectional area is inversely proportional to the average size of the individual blebs. In many grains the blebs are restricted to the interior; the margins of these grains show no perthitic structure. These exsolution blebs commonly show polysynthetic twinning.

Quartz in these charnockites is clear and contains no significant amount of inclusions.

The composition of hypersthene ranges from Fs_{35} to Fs_{40}.[1] Most grains are slightly pleochroic: X = pink, Y = pink, Z= gray green. Biotite generally occurs along fractures in the hypersthene, but nowhere has the biotite replaced more than a small portion of the hypersthene. Fig. 10 shows an example of this biotitization. All the grains are anhedral, and most of them "wrap-around" the surrounding grains as shown in Fig. 11.

The augite present is a green, nonpleochroic variety and has an average birefringence equal to 0.022. It generally occurs an anhedral, equant grains, though larger poikilitic grains are present in some specimens. These larger poikilitic grains "wrap-around" the surrounding grains. Augite occurs also along the margins of grains of hypersthene. In Fig. 13 augite completely surrounds a grain of hypersthene.

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[1]The composition of the hypersthene is based on the determined values of maximum birefringence.

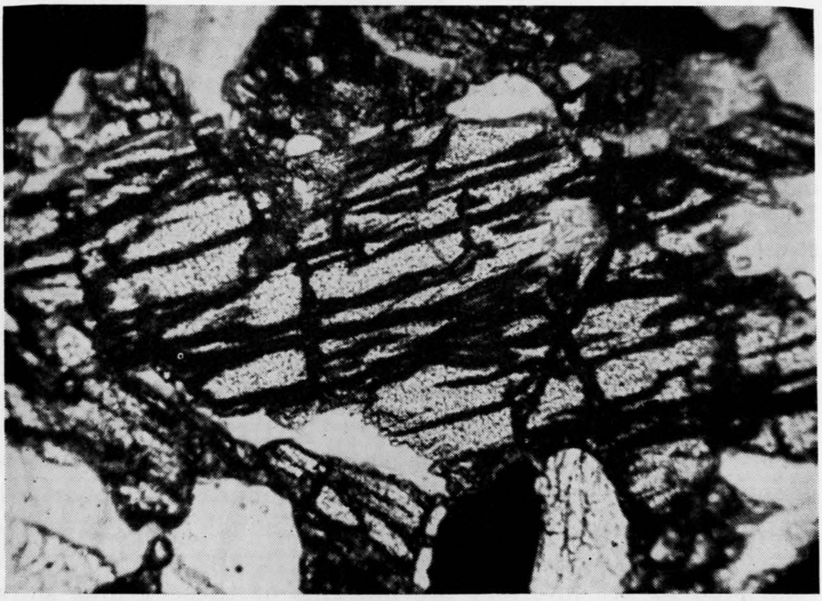

Fig. 10. Biotitization along fractures in hypersthene. Charnockite from one mile southeast of Thomaston and 0.1 miles up creek from road junction 882. (70X, crossed-nicols)

Fig. 11. An irregular grain of hypersthene (H) that wraps around a grain of quartz (Q). Hypersthene granodiorite from creek 0.45 miles west of the Thomaston Public Square. (80X, crossed-nicols)

There is generally a relationship between the crystallographic orientation of hypersthene and the crystallographic orientation of the augite next to and surrounding it. The extinction angle of the augite is 45° from that of the hypersthene. The orientation of the augite apparently is dependent on the orientation of the hypersthene. This relationship is treated further in the section, coronas.

Some of the biotite occurs as flakes which have an average long dimension of 1 mm. Generally these flakes have been replaced in part by garnet as shown in Fig. 17. Most of the biotite, however, is present as small, scattered flakes. Biotite occurs also in "nests" with quartz and augite, and some of these "nests" are surrounded by a corona of garnet. One of these "nests" is shown in Fig. 12.

Some of the garnet occurs as large subhedral to anhedral grains, generally about 1 mm. in width. Most of the garnet is present as coronas around biotite, augite, hypersthene, hornblende, and apatite where plagioclase is the next adjacent mineral. Where quartz or microcline occur next to one of the above mentioned minerals, no corona has formed. In Fig. 13 a grain of hypersthene is surrounded by augite, which is in turn surrounded by a corona of garnet. In Fig. 12 a layer of quartz lies between a grain of hypersthene and the corona of garnet. In Fig. 14 the garnet is vermicular. The synantetic structures are discussed in the section, Coronas.

Zircon, apatite, and ilmenite occur in all specimens examined. Some specimens contain a few scattered grains of a dark green hornblende. Sphene was not observed in any section.

Myrmekite is present in all specimens and is generally found as embayments into microcline-microperthite.

Chlorite is present along the cleavage of a few grains of biotite. A little calcite in irregular masses cuts indiscriminately across grains of other minerals.

Rosiwal analyses of two typical charnockites from the Thomaston quadrangle are given in Table VI (Spec. 1 and 2). The mineral compositions of the members of the charnockite series are discussed together in the section on Genesis.

Fig. 12. Coronas of garnet (G) separate plagioclase (P) from hypersthene (H) and from a "nest" (n) of quartz and biotite. A layer of quartz (Q) lies between the hypersthene and its corona of garnet. Same locality as Fig. 10. (80X, crossed-nicols)

Fig. 13. Double corona. A grain of hypersthene (H) is surrounded by a corona of augite (A), which is surrounded in turn by a corona of garnet (G). Same locality as Fig. 10. (50X, crossed-nicols)

Hypersthene-quartz monzonite. The mineral species present in hypersthene-quartz monzonite are the same as those present in charnockite. The fabric is allotriomorphic, and the average grain size is from 0.5 mm. to 2 mm. Porphyritic varieties carry phenocrysts up to 30 mm. in width.

In all specimens studied the plagioclase is close to An_{35}. It is twinned and zoned in the same manner as the plagioclase in the charnockite.

The potassium feldspar is microcline-microperthite and has the same characteristics as that in the charnockite.

Quartz shows no significant amount of inclusions.

The hypersthene ranges in composition from Fs_{40} to Fs_{45}. Its other characteristics are like those of the hypersthene in the charnockite.

Augite is pale green and nonpleochroic. The maximum birefringence is generally 0.023 and $z : c = 45°$. It occurs as isolated grains and as a replacement of hypersthene.

Table VI

	1	2	3	4	5	6	7	8	9
Plagioclase	8%	21%	29%	26%	37%	40%	40%	38%	38%
Anorthite content of plagioclase	30	30	35	35	40	40	55	65	75
Microcline-microperthite	47%	39%	38%	35%	25%	12%			
Quartz	30	20	20	18	16	15			
Hypersthene	2	5	5	11	11	11	23	11	18
Ferrosilite content of hypersthene	40	35	40	45	45	40	50	25	25
Garnet	6%	7%	4%	5%	5%	13%	21%	15%	15%
Brown hornblende								6	6
Actinolite								26	21
Others	6[1])	8[1])	4[1])	5[1])	6[1])	9[1])	16[2])	4[3])	2[3])
Total mafic	8	13	9	16	17	20	27	43	45
Specific Gravity	2.77	2.78	2.80	2.82	2.84	2.90	3.14	3.08	3.17

[1]) Includes principally biotite and augite but also some apatite, zircon, and ilmenite.

[2]) Includes 12% ilmenite in addition to apatite and biotite.

[3]) Augite, rutile, apatite, ilmenite, and pyrite.

1 Charnockite. 1.1 miles S45°W Thomaston Public Square at supplementary bench mark 735. (Sample taken from excavation)
2 Charnockite. One mile southeast of Thomaston Public Square and 0.1 miles up creek from road junction 882.
3 Hypersthene-quartz monzonite. From a well 300 feet north of junction of Drake Branch with Potato Creek.
4 Hypersthene-quartz monzonite. Swift Creek east of Mulberry Level.
5 Hypersthene granodiorite. One mile southeast of Thomaston Public Square and 0.2 miles up creek from road junction 882.
6 Hypersthene granodiorite. Creek 0.45 miles west of the Thomaston Public Square.
7 Norite. Fourth Branch 0.6 miles N65°W of Mulberry Level.
8 Hypersthene gabbro. Swift Creek 0.75 miles N45°W of Redbone Crossroads.
9 Hypersthene gabbro. Little Swift Creek 0.45 miles N50°W of road junction 581 five miles southeast of Thomaston.

Biotite is generally present as small flakes (0.1 mm. long dimension) in "nests" with quartz and as scattered flakes. Many larger flakes are present, but they have been replaced to a great extent by garnet. Radiohaloes are not found in the biotite even though inclusions of zircon are common.

Garnet not only forms coronas around biotite where plagioclase is the immediately adjacent mineral but also invades the biotite as shown in Fig. 17.

Green hornblende is a more abundant component of some of these rocks and in some specimens should be considered a varietal mineral.

All specimens contain zircon, apatite, ilmenite, and myrmekite.

Rosiwal analyses of two hypersthene-quartz monzonites are given in Table VI (Spec. 3 and 4).

Hypersthene granodiorite. The mineral species present in hypersthene granodiorite are the same as those in charnockite and in hypersthene quartz-monzonite. The principal difference is that the ratio of minerals present is different, and the plagioclase is generally An_{40}. The fabric is allotriomorphic, and the average grain size is 1 to 2 mm. Porphyritic varieties carry phenocrysts up to 30 mm. in width.

A greater percentage of mafic minerals have coronas in this group than in the more silicic groups simply because of the greater abundance of plagioclase, the **sine qua non** for this type of corona.

Rosiwal analyses of two hypersthene granodiorites are given in Table VI (Spec. 5 and 6).

Norite. The norite member of the charnockite series differs from the more silicic members principally in the absence of potassium feldspar, zircon, myrmekite, and significant quartz. The fabric is allotriomorphic, and the average grain size is 0.5 mm.

The plagioclase is An_{55}. Quartz is present as scattered grains and in coronas.

The composition of hypersthene in one of these rocks is Fs_{50}, and in another it is Fs_{30}. However, the rock containing Fs_{30} also carries brown hornblende, whereas that containing Fs_{50} carries no other mafite in significant quantity.

Garnet occurs as coronas around hypersthene, hornblende, apatite, and ilmenite.

Ilmenite is present in greater amount than in any other member of the series. Small amounts of biotite and green hornblende are present, but zircon is absent. Myrmekite is absent.

The Rosiwal analysis of a norite is given in Table VI (Spec. 7).

Hypersthene gabbro. The hypersthene gabbro member of the charnockite series differs from the more silicic members principally in the presence in some specimens of brown hornblende, coronal actinolite, and accessory rutile. Like the norite member, the gabbro member carries no potassium feldspar, zircon, myrmekite, or significant quartz. The fabric is allotriomorphic, and the average grain size is 0.5 to 1 mm. The most characteristic feature of the gabbro is a well-developed coronal structure. All mafites are surrounded by coronas of garnet where plagioclase is the immediately adjacent mineral.

Quartz is present only in coronas.

Plagioclase in specimens from different localities ranges from An_{65} to An_{75}. Most grains are well twinned and show no zoning. Those grains that exhibit zoning are more sodic in the outer zones. The outer zone of one grain is An_{15}. Since the zoning is limited to the margins of the grains in the more silicic varieties, it may be that the coronal growths in the gabbros have replaced completely the zoned portions of many grains of plagioclase.

Hypersthene is Fs_{30} and but slightly pleochroic. In this the most mafic member the magnesium content is greater than that in any other member of the series. In all more silicic members the iron content is greater.

Brown hornblende is present as large (1 mm.), isolated grains ($Z:c = 20°$), and the maximum birefringence is 0.020. The pleochroic formula is: X = pale green, Y = pale brown, and Z = light brown. Many of these grains contain small, irregular, isolated flakes of biotite, which are in optical continuity.

Actinolite is present as coronal aggregates of small (0.05 mm.) bleb-like grains. These aggregates occur around irregular and apparently residual grains of hypersthene. In all specimens the aggregates are surrounded in turn by coronas of garnet. This is illustrated in Fig. 16.

Augite occurs as colorless grains filled with minute, oriented blebs. Coronas of actinolite and garnet surrounds some grains of augite but not all of them.

Rutile and ilmenite are intimately associated, but it is not clear which has replaced which.

Rosiwal analyses of two hypersthene gabbros are given in Table VI (Spec. 8 and 9).

Related Rocks. The charnockitic rocks in the eastern part of the quadrangle are equigranular; those in the western part are porphyritic. Associated with the porphyries are porphyritic quartz monzonites and porphyritic granodiorites which carry little or no hypersthene. Among these porphyries there seems to be a gradation from rocks carrying hypersthene as the principal mafite to rocks carrying both hypersthene and biotite and finally to rocks carrying biotite as the principal mafite. However, no example was found in which there was any indication that one of these minerals developed at the expense of the other. Both seem to be primary.

A typical specimen in which biotite is the principal mafite is a porphyritic biotite-garnet quartz monzonite, which is composed of plagioclase (An_{30}), microcline-microperthite, quartz, biotite, and garnet. Minor amounts of hypersthene, apatite, zircon, ilmenite, pyrite, and myrmekite are present. Phenocrysts are up to 20 mm. in width; the grains of the ground mass average 0.1 mm. In hand specimen this rock is light gray; it does not have the dark color of the hypersthene-bearing rocks.

Coronas

The charnockite series of the Thomaston quadrangle is characterized by two kinds of coronas. In the one kind, the corona is composed of a synantetic mineral, that is, a mineral that forms only where two minerals of a particular composition meet (Sederholm, 1916, p. 1). In the second kind the corona is the product of a replacement that does not depend on two particular minerals being in juxtaposition.

The more common variety of corona in these rocks is a layer of garnet which separates a grain of plagioclase from a grain of hypersthene, augite, green hornblende, biotite, ilmenite, or even apatite. The garnet layer appears to be granular and is generally 0.1 mm. thick. In thin section these coronas appear as sinuous bands. Typical examples are shown in Fig's 12 and 13. Within a single thin-section, however, coronas are not present in every case where a grain of plagioclase is next to one of the above mentioned minerals.

In some rocks a corona of garnet lies between plagioclase and a "nest" of bleb-like grains of quartz and biotite, green hornblende, or augite. An example is shown in Fig. 12.

Though the coronas of garnet are generally of uniform thickness, there are many examples in which vermicular garnet has grown out into plagioclase. Rarely has the garnet invaded microcline-microperthite, as shown in Fig. 14. This example is the only one found in which coronas have developed that do not involve plagioclase. However, much exsolved plagioclase is present in the microcline-microperthite, and possibly this abundance is in some way responsible for the growth of the vermicular garnet.

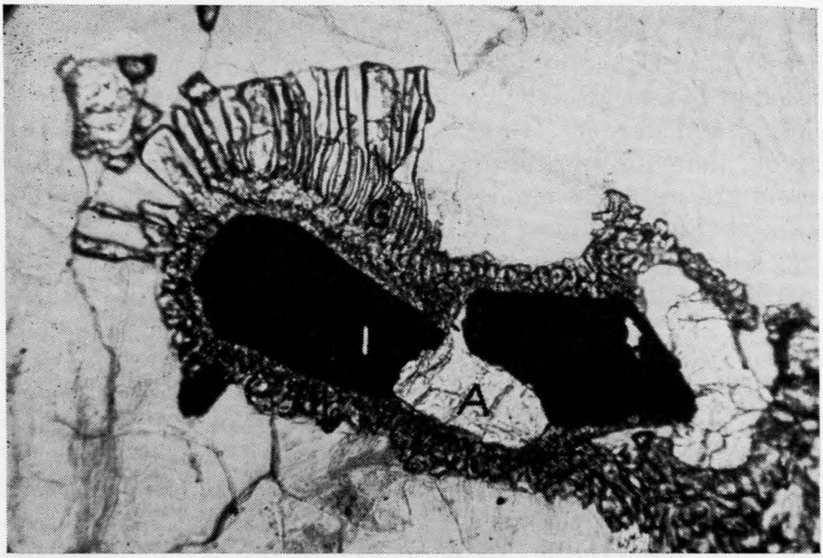

Fig. 14. Vermicular garnet (G) surrounding ilmenite (I) and apatite (A). Charnockite from Fourth Branch 0.6 miles west of road junction 724. (40X, plane polarized light)

Fig. 15. Augite (A) "invades" a grain of hypersthene (H). A grain of apatite (A) is partially surrounded by coronal garnet (G). Garnet-hypersthene quartz monzonite from Swift Creek 0.3 miles west of supplementary bench mark 714. (60X, plane polarized light)

A few of the garnet coronas are separated in part from the mafic minerals by a layer of quartz grains as shown in Fig. 12. These layers of quartz are one grain thick, and this thickness is about 0.1 mm.

There are two varieties of double coronas present. In the one variety an inner corona of augite lies between a grain of hypersthene and an outer corona of garnet. This is illustrated in Fig. 13. All the coronal augite has the same optical orientation, and its extinction angle is at 45° from that of the hypersthene. This relationship between the crystallographic orientation of the two minerals indicates that the augite took its orientation from the hypersthene. In some specimens, offshoots from the coronal augite "invade" a grain of hypersthene as shown in Fig. 15. The mode of origin of the inner corona of augite apparently differs from that of the outer corona of garnet. For example, hypersthene in some specimens is surrounded in part or completely by augite. The occurrence of augite around a grain of hypersthene, however, is not limited by the presence of any particular mineral on the other side. Therefore the augite cannot be regarded as a synantetic mineral. However, the garnet in the outer corona is a synantetic mineral.

The second variety of double corona has been found only in the hypersthene gabbro member of the series. In this variety an inner corona of actinolite separates a grain of hypersthene or augite from an outer corona of garnet. The corona of actinolite is generally of varying thickness and apparently has replaced the center grain of pyroxene to a greater or lesser extent. This variety of double corona is illustrated in Fig. 16. The coronas of actinolite may have been present before the coronas of garnet formed, or both types of corona may have formed as part of one process. The evidence is not clear which interpretation is correct.

In summary it may be said concerning the double coronas that an inner corona of augite is a replacement, but not a synantetic structure. It is not clear, however, whether or not an inner corona of actinolite is a synantetic structure. On the other hand, the outer coronas of garnet are synantetic structures and have the same characteristics as the single coronas of garnet.

Fig. 16. Double corona. An inner corona of Actinolite (A) separates a grain of hypersthene (H) from an outer corona of garnet (G). Hypersthene gabbro from Little Swift Creek 0.45 miles N50°W of road junction 581 five miles southeast of Thomaston. (65X, plane polarized light)

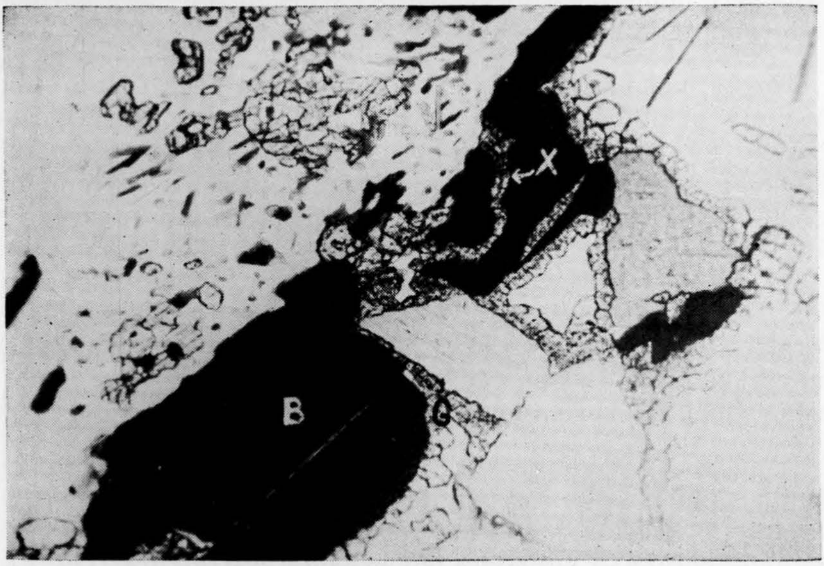

Fig. 17. Coronal garnet (G) around biotite (B). At "X" garnet "invades" the biotite. Hypersthene quartz monzonite from a well 300 feet north of the junction of Drake Branch with Potato Creek. (75X, plane polarized light)

In some specimens offshoots from coronas of garnet around biotite actually "invade" the biotite. An example of this is shown in Fig. 17. In this rock the garnet has formed apparently both as a synantetic mineral and as a replacement not dependent on two particular minerals being in juxtaposition.

Coronas of garnet in rocks of the charnockite series in Madras have been described by Holland (1900, p. 161), in Mysore by Rama Rao (1945, p. 84, 147), in Uganda by Groves (1935, pp. 183-185), and in Natal by Gevers and Dunne (1942, p. 192, 201). Coronas of garnet around hypersthene in hypersthene gabbro in Pennsylvania have been described by Bascom (1905, p. 313). These structures are apparently like those that occur in the charnockitic rocks of the Thomaston quadrangle. Most of the coronas previously described in charnockitic rocks as well as most coronas of all kinds have been in intermediate and subsilicic rocks. In fact, Shand (1945, p. 264) has offered a hypothesis for coronal formation that required the presence of olivine. The coronas described in this report are unique, however, in that they occur in charnockite **(sensu stricto)** itself. Also the coronas surrounding apatite are unique; no reference in the literature to a similar structure could be found by the writer.

Since the development of a corona of garnet is dependent on the presence of a grain of plagioclase next to a mafic mineral, the rock must have been in an effectively solid state before synantetic growth began. Shand (1945, p. 264) has put forth the hypothesis that synantetic growths result from an instability of olivine under conditions of thermal metamorphism. He cites several examples of synantetic structures in rocks that have been invaded by younger intrusions.

There is no indication that the synantetic structures in the charnockite series of the Thomaston quadrangle could have formed by the process outlined by Shand. The synantetic growths do not involve olivine, but rather hypersthene, augite, hornblende, biotite, ilmenite, and even apatite. Also there is no evidence of later igneous intrusions that could have effected the thermal metamorphism considered necessary by Shand. The rocks in which these synantetic structures occur apparently consolidated at a high temperature. (The high temperature of consolidation is discussed in the section, Genesis.) It is possible that the equilibrium between plagioclase and mafic minerals, which obtained at the high temperature of consolidation, failed at a lower temperature. This lower temperature could still have been high enough so as not to have inhibited readjustment. The synantetic structures may have resulted from just such a readjustment.

In summary it can be said that synantetic structures as shown by the Thomaston rocks are not restricted to the subsilicic rocks but are common also in hypersthene granite (charnockite). The conditions for forming synantetic structures are probably favored in those rocks that consolidate at a temperature high enough so that on cooling an instability sets-up before the temperature becomes low enough to inhibit readjustment. However, the cause of synantetic structures remains a mystery that can be solved only by careful study.

Genesis

In Table VI are listed the Rosiwal analyses of ten rocks of the charnockite series from the Thomaston quadrangle. They are arranged from left to right in order of increasing calcium content of the plagioclase. In the same order the percentage of both quartz and microcline-microperthite present decreases. With minor exceptions the percentage of plagioclase and hypersthene increases. The exceptions may be due in large part to the growth of coronal garnet at the expense of hypersthene and plagioclase. Nearly all the garnet is coronal and shows no systematic variation in percent present. With one exception the total amount of mafic mineral increases. Zircon is present in all except the three most mafic rocks.

There is only one important exception to these variations. The ferrosilite content of the hypersthene should vary inversely with the basicity of the rock (Welch, 1914, p. 446). The hypersthene in the hypersthene gabbro does contain less ferrosilite than the more silicic members of the series. There is no other systematic variation, however. Probably the presence of biotite along with the hypersthene reflects an evolution of mafic minerals that is obscure and cannot be determined.

The simultaneous variation in ratio of minerals present and variation in composition of plagioclase in the rocks of the charnockite series in the Thomaston quadrangle correspond closely with that demanded by the concept of a liquid line of descent (Bowen, 1928, pp. 92-124). If these rocks had evolved by any process other than by crystallization form a rock melt, they would be different from what they are now.

First, relict minerals would probably be present, particularly relicts of the mineral that gave rise to hypersthene. In no rock, however, does hypersthene show any indication of having been derived from another mineral, but rather it is the primary mineral from which small amounts of other minerals have been formed. In no case is there any indication of a mineral essential to a charnockitic rock having been derived from another mineral.

Second, if these rocks had formed without having been a magma, the variation in mineral composition would not correspond so completely to the variations expected in a liquid line of descent. The percentage of quartz and potassium feldspar would not vary so closely with the sodium content of plagioclase. Zircon would not be confined to the more silicic varieties. The percentage of plagioclase and of total mafic minerals would not vary so closely with the calcium content of plagioclase. The variation pattern of the minerals present is one of change from assemblages of high melting point to assemblages of low melting point. A series of so closely related rocks that shows such a systematic variation in mineral composition can have originated only through differentiation of a magma.

The nature of the magma from which the charnockitic rocks were derived is indicated by the unusually large amount (up to 60%) of the exsolved plagioclase in the potassium feldspar. When the potassium feldspar first crystallized, it must have held in solid solution an unusually large amount of plagioclase, a condition that reflects a high temperature of consolidation. Also the poorly developed grid-twinning of the microcline, according to Kohler (1948, p. 55), is indicative of a high temperature of consolidation. This high temperature of consolidation was probably the result of a low water content of the magma.

The significance of the porphyritic quartz-bearing phanerites, which carry little or no hypersthene, is not clear. These rocks mark a gradation from normal quartz-bearing phanerites to charnockitic rocks. Since the gradation is among the primary minerals, the defining characteristics of the charnockitic rocks are determined before or during consolidation of the magma. The charnockitic rocks are probably heteromorphic derivatives of an otherwise normal magma. It is not clear just why hypersthene formed instead of biotite. It may be that the content of water in the magma is the determining factor.

The origin of the magma itself is a rather speculative subject and is not discussed in this report.

The dark color of the feldspars in the rocks of the charnockite series may be due to submicroscopic exsolution phenomena. The cause of the blue color of the quartz is obscure.

Mode of Emplacement

The trend of the foliation of the invaded Jeff Davis granite and schist-gneiss migmatite is not influenced by the presence of the bodies of charnockitic rocks. Therefore the magma from which the charnockitic rocks were derived made room for itself by removal of material rather than by "shouldering-aside." There is little evidence, however, regarding the manner in which the removal of material was effected. There is no indication that the charnockitic rocks contain any assimilated material. Emplacement by stoping is a possibility, but deep weathering has obscured the evidence of the contact zones.

The large body of rocks of the charnockite series east of Thomaston is possibly not one continuous mass but rather a series of dikes and small stocks. If this interpretation is correct, any Jeff Davis granite that might be within the area mapped as charnockitic rock is so deeply weathered that none is now recognizable.

Structure

On fresh fracture the charnockitic rocks show no structure; the dark color masks any foliation present. In the weathered outcrop, however, a foliation is revealed and its strike and dip are determinable. The strike of the foliation is reflected also in the grain of the topography. Several small streams have developed subsequent courses parallel to the strike.

Age and Correlation

The mass in the southwest portion of the Thomaston quadrangle, which is mapped as rocks of the charnockite series, extends into the Warm Springs quadrangle where it was mapped as Cunningham granite by Hewett and Crickmay (1937, Plate III). Since no granite was found in this mass, the name Cunningham granite is not used. However, the Cunningham granite of the Warm Springs quadrangle and the charnockitic rocks of the Thomaston quadrangle probably represent a genetically related series of intrusions.

All that can be said concerning the age of the rocks of the charnockite series is that they are younger than the Jeff Davis granite and older than movement along the Goat Rock fault. They may be related in time to the hypersthene syenites in Virginia (Watson, 1916, p. 106). However, this correlation cannot be proved.

The Charnockite Problem

The first published descriptions of the rocks in India that are now known as the charnockite series appeared in 1836. However, the true nature of these rocks was not determined until after the polarizing microscope was introduced into petrography. In 1892 the occurrence of a hypersthene granite in India was announced (Rec. Geol. Surv. India, 1892). By coincidence one year later J. H. L. Vogt (1893, p. 6) independently described a series in Norway that corresponds to the hypersthene rocks of India.

At about the same time that the hypersthene granite was being studied "the tombstone of Job Charnock, the founder of Calcutta, was discovered by the Rev. H. B. Hyde in St. John's Churchyard, Calcutta, and when it was found that the tombstone was made of the same hypersthene granite (which was at the time thought to be a new type of rock), the name **charnockite** was suggested for it in honor of the man who was the unconscious means of bringing the first specimen of this interesting rock to the city which ultimately became the capital of India." (Holland, 1900 p. 134).

This investigation of the charnockite series by the Geological Survey of India culminated in the classic Memoir by Thomas H. Holland in 1900. Holland put a wise limitation on the use of the name charnockite. "Charnockite is a convenient name for a quartz-feldspar-hypersthene-iron ore rock in the charnockite series, and not a name for **any** hypersthene-granite occurring in other petrographical provinces." Holland states further that, "unless a similar formation found in another country can be proved to be a genetic relation of the typical exposures described in this paper, it is hoped that the name charnockite will never be used outside India." (Holland, 1900, p. 131)

The charnockitic rocks of the type locality in Madras have certain features that set them apart as a distinct group of rocks. The defining characteristics of these rocks are:

1. In hand specimen all members of the series are blue gray to dark green. The dark color is due to the presence of blue quartz and blue feldspar. The dark color so masks the mineral composition of the rock that charnockite might easily be confused with a typical norite member of the series.

2. Hypersthene is an invariable constituent.

3. The potassium feldspar is generally microcline. In three specimens from the type locality studied by the writer, all potassium feldspar is microcline-microperthite similar to that in the charnockitic rocks of the Thomaston quadrangle.

4. Sphene is absent.

Holland states that quartz generally contains innumerable acicular inclusions. However, no such inclusions were present in the quartz in the specimens from the type locality studied by the writer, nor could H. S. Washington (1916, pp. 324, 326) find any of these inclusions in the specimens from the type locality that he studied. Therefore the presence of acicular inclusions in quartz should not be considered a **sine qua non** for rocks of the charnockite series.

Holland lists also a "granular fabric" as essential. The fabric, however, is not necessarily primary and should not be considered a defining characteristic.

Rocks with the four characteristics listed above occur as a consanguineous series in the type locality. Any other series with these characteristics must be considered a charnockite series. However, the fortuitous occurrence of a rock having the above four characteristics does not mean that such a rock can be considered to be a member of a charnockite series. A comagmatic series should be present before the name is applied to it.

Though the charnockite series is not widespread in its occurrence, it has been found in metamorphic terranes in several parts of the world. Besides those in India, noteworthy occurrences have been described in Virginia (Watson 1916), in Ceylon (Adams, 1929), in Uganda (Groves, 1935), in the Ukraine (Lebedev, 1937), in the Adirondacks (Buddington, 1939), in Natal (Gevers and Dunne, 1943), and in southern Finland (Parras, 1943; Hietanan, 1947). Writing on charnockitic rocks in the Outer Hebrides, Davidson (1943, p. 103) cites occurrences of charnockitic rocks in southern Norway, Ivory Coast, Adelie Land in Antarctica, Gold Coast, Angola, Sierra Leona, northeastern Greenland, the Kola Peninsula, northern Siberia, and Chinese Turkestan.

Holland gives conclusive evidence for an igneous origin of the charnockite series in Madras. This evidence consists of the form and structure of the massif, dikes extending from the main mass, contact metamorphism of the surrounding rocks, and inclusions of older foreign rocks. (Holland 1900, p. 242).

The charnockitic rocks of Madras extend into Mysore where they have been studied extensively. In a recent paper on the Mysore occurrences, Rama Rao (1947, p. 162) states that he, "regards the charnockites not as belonging to a petrograaphic province as originally interpreted—namely the differentiated phases of crystallization of a normal plutonic magma—but as a metamorphic province wherein the combined effects of a repeated series of alterations under different periods of metamorphism, of a composite series of rock formations of different ages, have given rise to a series of hypersthene granulites of very variable composition."

The conflicting views of Holland and Rama Rao illustrate quite clearly the status of the "charnockite problem" as well as the "granite problem." It may be that rocks which are petrographically similar to those of the charnockite series have been formed from previously existing rocks by some metamorphic process. However, a charnockite series must be a petrographic series, that is, the members of the series must have a systematic variation in composition. It does not appear probable that a petrographic series can be formed by any process other than by differentiation from a magma. Any igneous-looking rocks or charnockitic-looking rocks that have been formed from previously existing rocks by a metamorphic process cannot be regarded as a comagmatic series. As by definition the rocks of the charnockite series are igneous, the name should not be applied to non-igneous rocks.

The petrologic unit discussed in this section ranging from hypersthene gabbro to hypersthene granite appears to meet all the requirements for constituting another representative charnockite series.

BIOTITE-OLIGOCLASE GNEISS AND EPIDOTE AMPHIBOLITE GNEISS

Introduction

The terrane south of the Goat Rock fault is entirely different from that north of the fault, and there is apparently no possibility of correlation within the quadrangle of any lithologic or structural features across the fault. The biotite-oligoclase gneiss is interbedded with the epidote amphibolite gneiss, and no attempt was made to differentiate these rocks in mapping. Intrusive into these rocks is a hornblende-biotite granite.

Historical Review

On the State map these rocks are shown as biotite gneiss of the Carolina series and are part of a belt about 10 miles wide and 120 miles long which extends across the center of the State. The poor outcrops and the general complexity of the geology have not encouraged investigation. These rocks were mentioned briefly by Galpin (1915 p. 72), who described them as "the usual variety of schists and gneisses." They were called the Uchee belt by Hewett and Crickmay (1937, opposite p. 4).

Areal Distribution

The biotite-oligoclase gneiss and epidote amphibolite gneiss underlie an area of twenty-seven square miles within the Thomaston quadrangle. Exposures of all varieties may be seen along U. S. Route 19 from one mile both north and south of Swift Creek. Some belts are composed entirely of epidote amphibolite gneiss; more generally, however, this gneiss is interbedded with a leucocratic biotite-oligoclase gneiss. There are all gradations from belts composed entirely of one to belts composed entirely of the other. A more mafic biotite oligoclase gneiss occurs in isolated outcrops, but it is not known whether it grades into the leucocratic variety.

The leucocratic biotite-oligoclase gneiss is the predominant rock type of this terrane. The epidote amphibolite gneiss and the more mafic biotite-oligoclase gneiss are present in about equal proportions.

Weathering Features

None of the rocks of this terrane is characterized by unusual resistance or susceptibility to weathering. The most striking feature developed by weathering is a strong grain in the topography, which reflects the well developed foliation and lamination of these gneisses.

The soil formed from the more mafic biotite oligoclase gneiss ranges from dull gray to light red. Its color is not distinctive. Soil derived from the leucocratic biotite-oligoclase gneiss and from the epidote amphibolite gneiss is generally light gray and very distinctive. In some places, however, the soil developed from epidote amphibolite gneiss is various shades of red.

Petrography

There are no apparent systematic variations among the rocks of this terrane. The epidote amphibolite gneiss is strongly laminated and is probably a metamorphosed dolomitic rock or metamorphosed tuff. Associated with this gneiss is a peculiar garnet-anorthite-quartz granulite which probably developed from a sedimentary layer of unusual composition.

The biotite-oligoclase gneisses can be divided into leucocratic varieties and more mafic varieties. The former is intimately associated with the epidote amphibolite gneiss and is probably of sedimentary origin; the latter yields little evidence concerning its origin. Some of these biotite-oligoclase gneisses are mylonites that are recrystallized (blastomylonites) and are discussed in the chapter on Structure.

Epidote amphibolite gneiss. In the hand specimen this variety is generally laminated; the alternating green and light gray layers range from a fraction of an inch to a few feet in thickness, and even the thin layers have a lateral extent of several feet.

A typical specimen from a more mafic layer is composed of green hornblende, low-iron epidote, plagioclase (An_{35}), sphene, apatite, and zircon. The fabric is granoblastic. The grains are generally equant and range from 0.2 mm. to 1 mm. in diameter. A Rosiwal analysis of this rock is given in Table VII (Spec. 1).

Table VII

	1	2a	2b	3	4	5
Plagioclase	10%	33%	31%	29%	37%	37%
Quartz		46	32	62	55	47
Hornblende	42	19				
Epidote	46		37			
Biotite					3	10
Muscovite					5	5
Garnet				7		1
Others	2[1])	2[2])		2[3])	tr[4])	tr[5])

[1]) Zircon, sphene, and apatite.
[2]) Zircon, sphene, apatite, and ilmenite.
[3]) Augite, sphene, apatite, hornblende, allanite, and magnetite.
[4]) Garnet and ilmenite.
[5]) Zircon, pyrite, and magnetite.
1 Epidote amphibolite gneiss. 1.0 miles N70°W of B.M. 659 on the Talbotton Road.
2 Epidote amphibolite gneiss. 1.5 miles N55°W of top of Ten Acre Rock. 2a is a hornblende layer, and 2b is an epidote-rich layer.

3 Garnet-anorthite-quartz granulite. Road 1.4 miles N30°W of Parker Bridge.
4 Biotite-oligoclase gneiss, leucocratic variety. 0.1 miles north of Daniel School.
5 Biotite-oligoclase gneiss, more mafic variety. 0.9 miles west of B.M. 659 on Talbotton Road.

In some specimens the alternating layers have strongly contrasting mineral compositions. In one example layers composed of hornblende, plagioclase (An_{35}), and quartz alternate with layers composed of epidote, plagioclase (An_{35}), and quartz. A Rosiwal analysis of each of these two kinds of layers is given in Table VII (Spec. 2a and 2b).

Garnet-anorthite-quartz granulite. Within the epidote amphibolite gneiss terrane are several lenses of rock with unusual mineral composition. One of these rocks consists principally of quartz, anorthite (An_{90}), and garnet. A smaller amount of augite, sphene, apatite, hornblende, allanite, and magnetite is present. The fabric is granoblastic, and the average grain size is 0.5 mm. A Rosiwal analysis of this rock is given in Table VII (Spec. 3).

Biotite-oligoclase gneiss, leucocratic variety. Interbedded with the epidote amphibolite gneiss and also forming thick belts by itself is a light yellowish-gray gneiss. This variety is typically composed of plagioclase (An_{15}), quartz, biotite, muscovite, garnet, and ilmenite. The texture is granoblastic, and the grain size ranges from 0.1 mm. to 0.5 mm. A Rosiwal analysis of this rock is given in Table VII (Spec. 4).

Biotite-oligoclase gneiss, more mafic variety. Some belts in this terrane are composed of rock richer in biotite. A typical specimen from such a belt is made up of plagioclase (An_{25}), quartz, biotite, muscovite, garnet, zircon, and pyrite or magnetite. The fabric is granoblastic and the average grain size ranges from 0.5 mm. to 2 mm. A Rosiwal analysis of this rock is given in Table VII (Spec. 5).

The more mafic variety differs from the leucocratic variety in that the former contains more biotite, carries a more calcic plagioclase and is coarser grained. However, these two varieties of biotite oligoclase gneiss may be facies of one rock type.

Structure

The epidote amphibolite gneiss is characterized by a particularly well-developed foliation. Layers rich in hornblende and epidote alternate with layers containing little or no mafic mineral. Some layers less than one-quarter inch thick persist at least five to ten feet along the strike and probably could be traced a greater distance if outcrops were better. The foliation is generally undisturbed, though in some places it is deformed into recumbent folds which have an amplitude of one to ten feet. In other places these rocks are complexly faulted. These deformational features are discussed in the chapter on Structure.

There are several alternating belts of epidote amphibolite gneiss and leucocratic biotite-oligoclase gneiss, each of which grades into the next contiguous belt. In passing stratigraphically from one belt to another, one rock type appears within the other first as subordinate layers. Then these layers increase in number and size and finally predominate to form the next belt.

The more mafic biotite-oligoclase gneiss is moderately to strongly foliated, and the foliation in some places is deformed into small, recumbent folds which have an amplitude of one to twelve inches. The structural relation between this rock type and the other rock types of this terrane is not clear. However, since there is no apparent structural discordance in this terrane, all the rocks may be part of one conformable sequence.

Genesis

The mineral assemblages and fabrics of the rocks of this formation indicate that all varieties are moderately metamorphosed. The well-developed lamination is probably original sedimentary bedding. However, it is not clear whether all the rock types were originally sediments derived from the destruction of older rocks. Any one of them, particularly the epidote amphibolite gneiss, may have been of volcanic origin. However, there is not enough evidence to determine whether the epidote amphibolite gneiss was originally a tuff or a dolomitic sediment.

The garnet-anorthite-quartz granulite, which occurs within the epidote amphibolite gneiss terrane, is best interpreted as a metamorphic derivative of a sedimentary layer. Its mineral assemblage could not have been derived from an igneous rock.

Age and Correlation

These rocks are called Carolina gneiss on the State Geologic Map. There is no positive evidence concerning their age other than that they are overlain by the Upper Cretaceous Tuscaloosa formation.

Throughout the Appalachian Piedmont province in Georgia, South Carolina, and North Carolina are belts of metamorphic rocks that have been called Carolina series. Associated with these rocks are amphibolites which Keith (1903, p. 2) called Roan gneiss. In the Thomaston quadrangle the epidote amphibolite gneiss bears a transitional relationship to the biotite-oligoclase gneiss as does the Roan gneiss to the Carolina series at the type locality of the Roan gneiss described by Keith (1903, p. 2). In describing the relationship between the two units Keith wrote, "That part of the Carolina series which is adjacent to the Roan gneiss contains some thin interbedded layers of hornblende-schist and -gneiss precisely like the Roan gneiss, constituting a transition between the formations, so that the boundary is somewhat indefinite." This relationship taken alone indicates the possibility that the Carolina series and the Roan gneiss are but one series instead of two. This interpretation would give substance to the possibility that the biotite-oligoclase gneiss could be correlated with the Carolina series and that the epidote amphibolite gneiss could be correlated with the Roan gneiss. However, Keith (1931, p. 3) later showed that the Roan gneiss is intrusive into the Carolina series. In the Thomaston quadrangle there is no indication that the epidote amphibolite gneiss is intrusive into the biotite-oligoclase gneiss. Therefore there is no basis for correlation of these rocks with the Carolina series and the Roan gneiss. In addition, the type localities for the Carolina series and the Roan gneiss are a great distance from the Thomaston quadrangle; several thrust faults intervene. It does not seem to the writer proper to project a correlation of metamorphic rocks through so many unknowns.

HORNBLENDE-BIOTITE GRANITE

Introduction

Intrusive into the biotite-oligoclase gneiss and epidote amphibolite gneiss is a hornblende-biotite granite. Since both natural and artificial exposures are few in the part of the quadrangle in which this granite occurs, its exact boundaries could not be mapped with much confidence. Some of the contacts as drawn on the map may be as much as a thousand feet off. However, the general outline of the mass as mapped is probably correct.

Historical Review

This unit as such has not been described in the literature. On the State map it is not differentiated from the surrounding rocks; all are classified under the general heading of biotite gneiss of the Carolina series.

Areal Distribution

The main mass of the hornblende-biotite granite underlies twelve square miles within the Thomaston quadrangle. Smaller bodies of the same rock occur both north and south of the main mass and are probably sills satellitic to it. Good exposures of this unit may be seen at Ten Acre Rock and along the Talbotton Road for two miles east of Collinsworth Church.

Weathering Features

The hornblende-biotite granite is exposed in the largest single outcrop within the quadrangle. Ten Acre rock is well named in that a large part of the south side of this hill is a broad, flat exposure of fresh granite. It is here that xenoliths of biotite-oligoclase gneiss occur within the hornblende-biotite granite. It is a question as to why there is such a large exposure here in contrast to the deep weathering generally characteristic of this and all feldspathic rocks in this region. Though it cannot be proved in this area, this resistance to weathering is probably due to a wide spacing of joints.

However, the biotite-hornblende granite shows generally little resistance to weathering and good outcrops are few. The soil derived from this rock is of various shades of red and gray and is of no value as an aid in mapping.

Petrography

With one exception, which proved to be a quartz monzonite, all specimens from this unit that were studied are granites. In view of the limited outcrops, however, there may possibly be facies or genetically related intrusions which are more mafic, but none were found. Mafic minerals are sparse in every specimen examined, and much of the rock is leucogranite. Where biotite is the principal mafic mineral, some hornblende is generally present; where hornblende predominates, some biotite is generally present. Biotite, however, is the most common varietal mineral.

A typical specimen in which biotite is the predominant mafite is composed of microcline, quartz, plagioclase (An_{10}), biotite, muscovite, zircon, and magnetite. The fabric is allotriomorphic, and the average grain size is 0.5 mm. A Rosiwal analysis of this rock is given in Table VIII (Spec. 1).

A typical specimen in which hornblende predominates over biotite is composed of microcline, quartz, plagioclase (An_{15}), hornblende, biotite, sphene, zircon, allanite, magnetite, and pyrite. The fabric is allotriomorphic, and the average grain size is 0.5 mm. This rock is a hornblende quartz monzonite. A Rosiwal analysis is given in Table VIII (Spec. 2).

The exposure at Ten Acre Rock is interesting in that xenoliths are present in the granite. The granite itself is of about average composition, representative of the whole unit. It is composed of microcline, quartz, plagioclase (An_{10}), biotite, and minor amounts of hornblende, sphene, zircon, epidote, magnetite, and ilmenite. The fabric is somewhat unusual and is discussed below in the section on Structure. The average grain size is 0.5 mm. A Rosiwal analysis of this rock is given in Table VIII (Spec. 3).

Table VIII

	1	2	3	4
Plagioclase	19%	28%	14%	26%
Microcline	37	28	39	11
Quartz	39	41	42	35
Biotite	5	tr	4	23
Hornblende		2	tr	
Others	tr[1])	1[2])	1[3])	5[4])

[1]) Muscovite, zircon, and magnetite.
[2]) Sphene, zircon, allanite, magnetite, and pyrite.
[3]) Sphene, zircon, epidote, magnetite, and ilmenite.
[4]) Sphene, hornblende, apatite, garnet, epidote, and allanite.
1 Biotite granite. One mile west of Ten Acre Rock and 0.2 miles north of road junction 567.
2 Hornblende quartz monzonite. Talbotton Road one mile southwest of Parker Bridge.
3 Biotite granite. Ten Acre Rock.
4 Xenolith in biotite granite. Ten Acre Rock.

In hand specimen and in thin-section the xenoliths from Ten Acre Rock are seen to be similar to the more mafic variety of biotite-oligoclase gneiss. The principal constituents are plagioclase (An_{10}), microcline, quartz, and biotite. Small amounts of sphene, hornblende, garnet, apatite, epidote, and allanite are present. The fabric is allotriomorphic, and the average grain size is 0.5 mm. A Rosiwal analysis of one of these xenoliths is given in Table VIII (Spec. 4).

Structure

The hornblende-biotite granite mass is an elongate body, the long axis of which is parallel to the strike of the internal foliation and lineation and parallel to the strike of the lamination in the invaded rocks. A weak foliation is present in the granite, and within this foliation there is a strong horizontal lineation. The lineation is the result of a preferred orientation of hornblende and biotite grains and of a concentration of these grains in streaks. The long axes of exposed sections of angular xenoliths are parallel to the lineation.

The fabric of the granite at Ten Acre Rock is different from the fabric of the enclosed xenoliths. In the xenoliths the mineral grains are generally equant. Also the external form of the xenoliths indicates that neither xenoliths nor enclosing granite have been deformed very much since consolidation.

The strong lineation of the granite therefore must have developed for the most part in the liquid state. In the granite, however, the quartz grains are platy, indicating some deformation in the solid state. These two apparently anomalous features can best be explained as a protoblastic effect (Weber, 1913, p. 777 and Becke, 1916, p. 248), that is, when the rock had just consolidated it was extremely hot and highly plastic, and further movement caused a flattening of the quartz grains. This movement was apparently strong enough to deform the yet plastic igneous rock without deforming the xenoliths.

It is not clear whether the lineation is parallel to the direction of flow (fabric axis "a") or normal to the direction of flow (fabric axis "b").

Genesis and Mode of Emplacement

The best indication that the hornblende-biotite granite was emplaced as a magma is the presence within it of angular, sharp-edged xenoliths, that are not surrounded by a reaction zone. These xenoliths contain a larger percentage of biotite than the enclosing granite. If the granite had formed by replacement of rock now represented by the inclusions, excess biotite would have resulted from the process and a "basic front" would have encroached on the unreplaced residual. No "basic front" has encroached on these xenoliths. Also the lineation in these rocks is without doubt a flow structure produced for the most part in the liquid state.

It may be that the several kinds of varietal minerals indicate assimilation of wall rock and that all rock varieties are facies of a single intrusion. However, each variety may represent a separate intrusion.

The mode of emplacement of the magma is obscure. The presence of xenoliths demonstrates some stoping. The widespread variation in mineral composition of the granite indicates that some assimilation has taken place. However, the elongate shape and conformable contacts in horizontal cross-section indicate that the body is sill-like in structure and that it was emplaced principally by forceful injection.

Age and Correlation

There is no evidence concerning the age of the hornblende-biotite granite except that it is older than the epidote amphibolite gneiss and biotite-oligoclase gneiss and younger than the movement along the Goat Rock fault.

The writer knows of no other unit with which this granite may be correlated.

STRUCTURE

Introduction

The Wacoochee belt is bounded by two thrust faults, the Towaliga fault on the north and the Goat Rock fault on the south. Both thrust faults are marked by a wide zone of distributive movement along which occur sheared rocks, mylonites, ultramylonites, and blastomylonites.

Though the Towaliga fault and the Goat Rock fault are regarded generally as separate faults, they are possibly parts of the same fault. See Fig. 24. According to this interpretation the Wacoochee belt is a window.

Structure of the Wacoochee Belt

The Hollis quartzite and the Manchester formation in the Thomaston quadrangle have been faulted and have been warped into open folds. The nature of some of this faulting and folding is shown in Fig. 18, which represents diagrammatically the structure of the quartzite member of the Manchester formation. Dorster Mountain is at the center of a structural saddle. Dipping off this saddle to the north and to the southeast, the quartzite dips under the upper schist member. On the southeast, however, a segment has been faulted up and is marked by Brooks Mountain and Kings Mountain. On the west and east of the structural saddle the quartzite dips back toward Dorster Mountain. The cross-sections in Plate II also illustrate the structure of these rocks.

The fault northeast of Atwater is not exposed, but its presence is demonstrated by the structural discordance between the quartzite member and the Hollis quartzite. The two south-

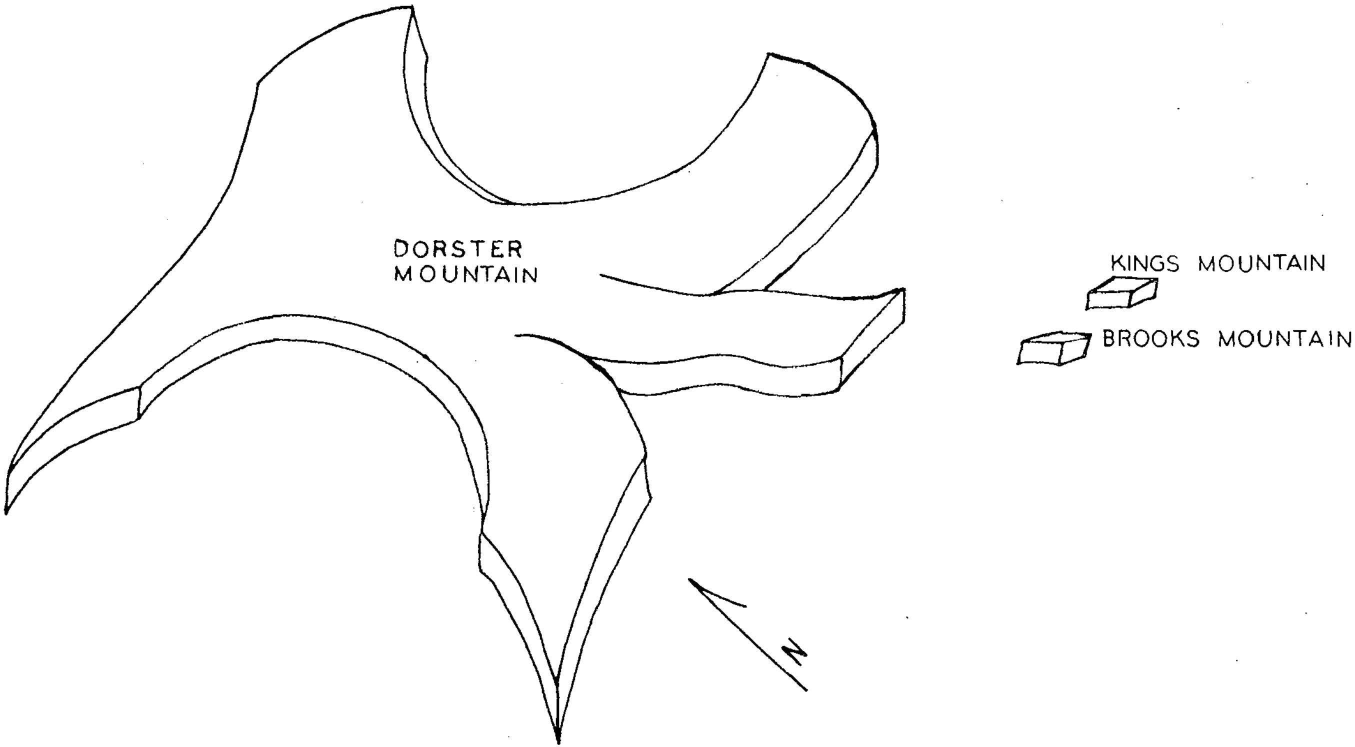

Fig. 18. Diagram of the quartzite member of the Manchester formation.

east-trending faults bounding the Brooks Mountain-Kings Mountain block are exposed in several places. Rather than a single fault bounding each side of the block, there are apparently several faults along which movement was distributed. In some places the schist next to the fault is undeformed; in others it is characterized by chevron folds. One fault outcrop is marked by a concentration of limonite about ten feet wide. The dips of these faults range from 60° to 90° both east and west.

The calculated throw on the faults that bound the Brooks Mountain-Kings Mountain block is from 3000 to 5000 feet. That this faulting is of such great magnitude and that it affects rocks of the schist-gneiss migmatite indicates that the faulting should continue on south into the Jeff Davis granite. Evidence of the continuation of at least one fault is found just south of the center of the quadrangle. Here Potato Creek takes an abnormally straight course, and there is a discordant contact between the Jeff Davis granite and the schist-gneiss migmatite. In fact, most of the discordant contacts between Jeff Davis granite and schist-gneiss migmatite are better explained as fault contacts rather than as cross-cutting igneous contacts.

The trace of neither the Towaliga fault nor the Goat Rock fault was found to be offset by the faulting in the Wacoochee belt. This indicates that the faulting in the Wacoochee belt is older than these thrust faults.

TOWALIGA FAULT

General Statement

The Towaliga fault is a northwest-dipping zone of distributive movement which extends for at least 125 miles across Georgia and Alabama. It was named by Crickmay (1933, p. 171) from exposures along the Little Towaliga River about sixteen miles northeast of Thomaston. The fault zone is marked throughout its extent by the presence of sheared rocks, mylonite, and ultramylonite.

Mylonites of the Fault Zone

The Towaliga fault crosses the extreme northwestern portion of the quadrangle. There is but one outcrop of cataclastic rock, which consists of mylonitized quartzite. In hand specimen this rock looks like a blue-gray chert. In thin-section it is seen to consist of grains that are less than 0.01 mm. in width. The mylonitized quartzite has been brecciated, and the fragments have been recemented with quartz. Since the mylonite is composed entirely of quartz, it has no visible S-planes. The mylonites along the Towaliga fault have been excellently described by Crickmay (1933, p. 171).

Unlike most faults in the Appalachian province, the Towaliga fault dips to the northwest. This feature is discussed in the section, Interpretation of the Thrust Faults.

GOAT ROCK FAULT

General Statement

The Goat Rock fault is a southeast-dipping zone of distributive movement which extends from the Thomaston quadrangle westward for sixty-five miles into Alabama where it is covered by sediments of the Atlantic Coastal Plain. Previous maps show the Goat Rock fault as entering the Thomaston quadrangle at the southwest corner and extending northward about three miles to a termination. The present study shows that instead of trending northward and stopping, the fault turns eastward again and shows no sign of dying out where it leaves the eastern edge of the quadrangle.

The Goat Rock fault was named by Crickmay (1933, p. 173) for the excellent exposures at Goat Rock Dam on the Chattahoochee River. The course of the fault is marked throughout its length by a broad belt of sheared rocks, mylonite, and ultramylonite, and blastomylonite. The width of the belt in plan is from one to two miles, and the dip of the shear planes is from 20° to 50° southeast.

Within the shear zone occur pyroxene-bearing rocks that resisted crushing and now form conspicuous unreduced masses. One of these is shown in Fig. 19. The foliation of

Fig. 19. Unreduced mass of pyroxene-bearing rock (P) within the shear zone of the Goat Rock fault. The foliation of the sheared rock bends around the resistant block (now reduced by weathering). This exposure is on the Talbotton Road one-half mile south of B. M. 548.

the sheared rock bends around the resistant block. The unreduced masses may be pieces of dikes that have been broken up, or they may be derivatives of calcareous sediments that had reached a medium rank of metamorphism before movement began on the fault.

Mylonites of the Fault Zone

Movement along the Goat Rock fault has powerfully affected rocks of the schist-gneiss migmatite, the charnockite series, the biotite-oligoclase gneiss and epidote amphibolite gneiss, and the hornblende-biotite granite, reducing them to mylonites.

Mylonitization generally follows a definite pattern. Quartz is the first mineral to be affected. Fracture of individual quartz grains is not gradual from the outside inward; a grain is shattered in equal amount throughout. Quartz grains that have been shattered and "strung-out" have no significant

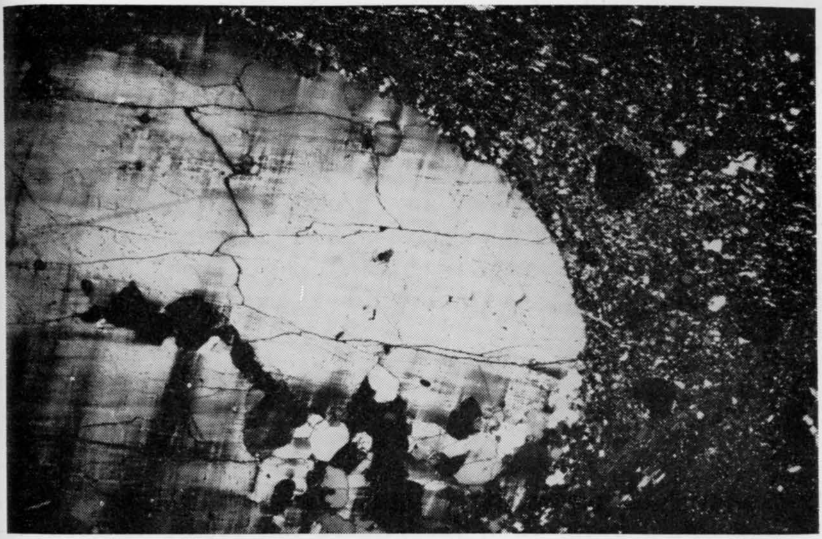

Fig. 20. Mylonitized charnockitic rock. A large porphyroclast of microcline-microperthite lies in an aphanitic matrix. Russell Branch 0.4 miles north of supplementary bench mark 663. (6X, crossed-nicols)

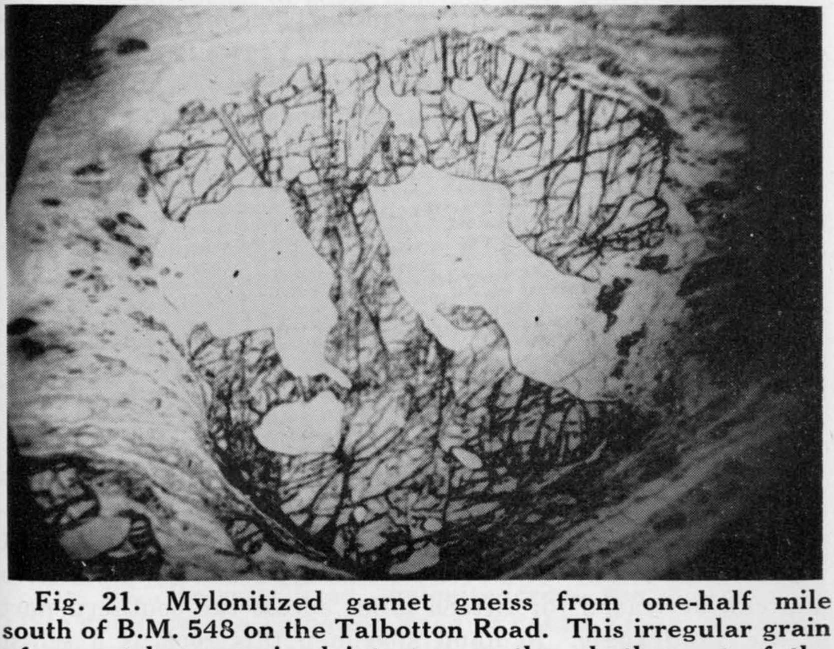

Fig. 21. Mylonitized garnet gneiss from one-half mile south of B.M. 548 on the Talbotton Road. This irregular grain of garnet has remained intact even though the rest of the rock has been reduced to a fine-grained material. (25X, plane polarized light)

open space between fragments. Therefore there must have been some recrystallization to effect this complete accommodation of grains.

Feldspars generally show much greater resistance to crushing than quartz. Destruction of an individual grain is from the outside inward. First, any projections on a grain are knocked off. By attrition pieces are then broken off the periphery until the grain is completely reduced. In Fig. 20 a large porphyroclast of microcline-microperthite lies in an aphanitic matrix.

Biotite breaks up quite readily into small flakes which form streaks through the rock.

Garnet resists crushing better than any other mineral observed. Very irregular grains, like that shown in Fig. 21, remain intact even when the rest of the rock has been reduced to a fine-grained material.

One easily gets the impression that while a rock is being mylonitized, the porphyroclasts are rolled along. The large resistant mass in Fig. 19 has manifestly been rolled to some extent, as its foliation is nearly at right angles to the foliation in the surrounding sheared rock. However, other evidence indicates that not all the porphyroclasts have necessarily rolled. In Fig. 22 a patch of undeformed sillimanite, biotite, and quartz lies in a sheltered area next to a porphyroclast of garnet. If this garnet had been rolled, the sillimanite, biotite, and quartz would have been caught in the movement affecting the rest of the rock and would have been torn from the garnet.

Feldspar porphyroclasts in one specimen have a "tadpole" structure; each porphyroclast has left a trail of finely comminuted feldspar behind it. This is an example of an "a" fabric lineation produced in the solid state.

Within the Thomaston quadrangle the Goat Rock fault is marked by mylonites that have been recrystallized. Recrystallization may have been in part paradeformational and in part postdeformational. One rock of this type is very distinctive and can be traced for fifteen miles across the southern part of the quadrangle. In hand specimen this rock is a schist characterized by unreduced grains of plagioclase (An_{25}) and quartz as well as by "buttons" composed of flakes of muscovite.

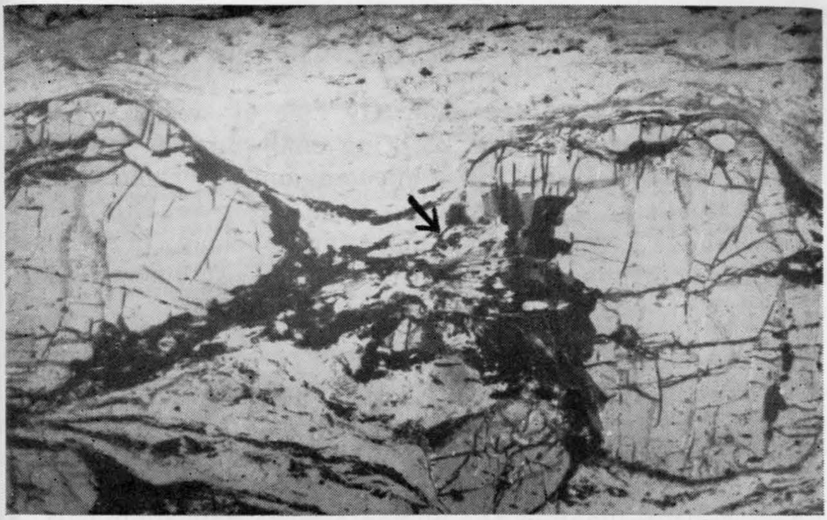

Fig. 22. Mylonitized sillimanite-garnet gneiss from the schist-gneiss migmatite. A patch of undeformed sillimanite, biotite, and quartz (indicated by arrow) lies in a sheltered area next to a porphyroclast of garnet. The specimen is from 0.2 miles northeast of road junction 658, which is about two miles southeast of Pleasant Hill. (8X, plane polarized light)

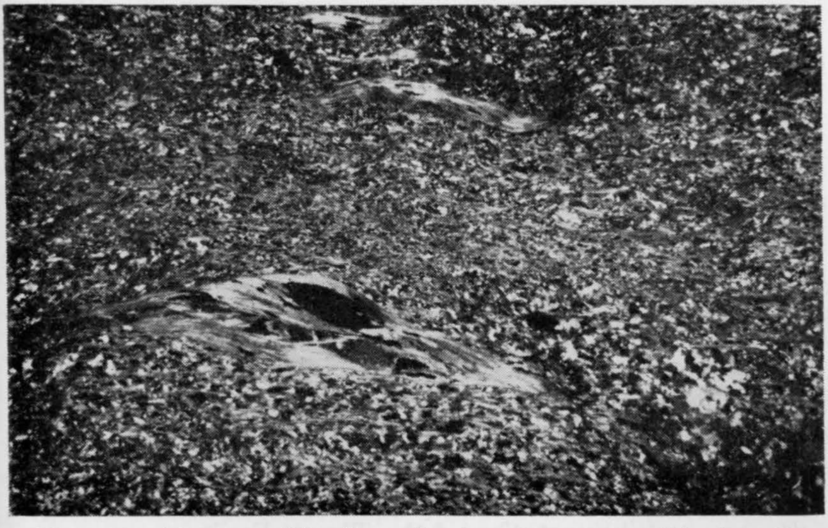

Fig. 23. Recrystallized mylonite from the biotite-oligoclase gneiss on the Talbotton Road at Potato Creek. "Buttons" of muscovite lie in an aphanitic matrix of plagioclase and quartz. One of the "buttons" has been twisted. (10X, crossed-nicols)

The porphyroclasts and "buttons" lie in an aphanitic matrix. In thin-section the muscovite in the "buttons" shows some postcrystallization deformation, but the plagioclase and quartz in the matrix are generally free of strain. Typical "buttons" are shown in Fig. 23. One small "button" has been twisted. This rock may be a blastomylonite derived from a rock of the same mineral composition. However, the muscovite may have developed from potassium feldspar. In this case the rock would be a diaphthoritic mica schist derived probably from a rock of the composition of a granite.

The question arises as to why some rocks go to mylonites and others go to blastomylonites. Since no significant amount of pore space is permanently created between the crushed mineral grains as a result of mylonitization, some recrystallization probably always accompanies the "milling" process. Where recrystallization has played a more important part, a blastomylonite is produced. Whether a mylonite or a blastomylonite forms is dependent on the nature of the rock, speed of deformation, and other factors. Grubenmann and Niggli (1926, p. 230) list four factors that favor recrystallization during deformation. They are:

1. Relatively high confining pressure.

2. High temperature.

3. Presence of solutions.

4. Relatively fine-grained (Furnishes greater surface for reaction).

It is not clear just what the relative importance of each of these factors was in the formation of the blastomylonites of the Thomaston quadrangle.

Within the shear zone of the Goat Rock fault the epidote amphibolite gneiss is complexly folded and faulted. Apparently this rock yields to deformational forces more readily by folding and faulting than by mylonitization.

Interpretation of the Thrust Faults

Structural data for deformation in the Appalachian province indicates, as is well known, that the active compressional force that has affected these rocks came from the southeast.

That the Towaliga fault dips to the northwest is not in accord with this picture. The Towaliga fault may be an overthrust from the northwest, an underthrust from the southeast, or an overthrust from the southeast which has been folded into its present position.

There is no positive evidence for or against the interpretation that this fault is either an overthrust from the northwest or an underthrust from the southeast. There is some indication, however, that the fault plane may have been folded. The structure of the Wacoochee belt is that of an irregular anticline. If the Towaliga fault and the Goat Rock fault could be raised to a horizontal attitude, the bedding of the rocks of the Wacoochee belt would be rendered more nearly horizontal and the structure would be less complex. This feature suggests the very interesting interpretation that the Towaliga fault and the Goat Rock fault are the same fault produced by a thrust from the southeast, that the fault plane has been folded, and that the Wacoochee belt is a window exposed by erosion through the overthrust block.

If it is correct that the Towaliga fault and the Goat Rock fault are but a single thrust from the southeast, the question remains as to what happens to the northward extension of the thrust plane. That both these faults are marked by such a broad belt of shearing indicates that horizontal displacement may have been very great. It is therefore possible that the Brevard fault, which parallels the Towaliga fault forty miles to the north, represents the northern extension of the Towaliga fault. A cross-section drawn according to this interpretation is shown in Fig. 24.

Contrary to the interpretation suggested above, A. S. Furcron (personal communication) states as follows:

"Although the Towaliga and Goat Rock faults on basis of reconnaissance seem to merge southwestward in Alabama, they diverge east of the Thomaston area in Georgia. The principal cleavage on the Towaliga mylonite is locally nearly horizontal or even definitely to the southeast, and the window interpretation, at present knowledge, almost demands that the Towaliga mylonite and the Brevard mylonite be correlative—with present limited work, a doubtful conclusion, because the

Towaliga trend and Brevard trend also diverge to the north and east."

The relationship of these faults to each other as well as their tectonic significance is far from being understood. The answer will come only after much more field work and extensive use of the method of multiple working hypotheses.

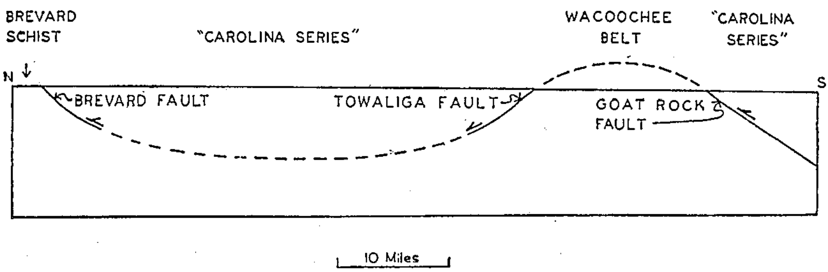

Fig. 24. Structure section drawn according to the interpretation that the Goat Rock fault, the Towaliga fault, and the Brevard fault are the same fault.

SKETCH OF THE GEOMORPHOLOGY

General Statement

The Thomaston quadrangle lies in the Greenville Plateau of the Central Upland of Georgia. The Greenville Plateau has been divided by LaForge (1925, p. 77) into a northern part, which lies between 800 and 900 feet, and a southern part, which lies at about 700 feet. Separating the two parts is the Pine Mountain district, which is characterized by ridges that rise 200 feet to 400 feet above the surrounding plateau.

The topography of the Thomaston quadrangle is fine-grained and well-dissected. The Flint River, Potato Creek, and many of the smaller streams flow southward and southeastward across the structure of the rocks. Some of the small streams, however, have developed subsequent courses parallel to the structure.

Erosion Surfaces

Within the Thomaston quadrangle many of the interfluves are marked by flat areas. Those near the Flint River are small, whereas those in the vicinity of Thomaston and south of Brooks Mountain cover more than a square mile. The flat areas are generally accordant and constitute part of the Greenville Plateau. Their altitudes decrease toward the south at the rate of about five feet per mile. The accordance of these surfaces suggests that they are remnants of a former post-mature erosion surface.

The southern margin of the Greenville Plateau is marked by an escarpment facing southward. According to LaForge (1925, p. 78) this escarpment was developed by stripping back of rocks of the Atlantic Coastal Plain. A southward projection of the Greenville Plateau would lie above the Coastal Plain rocks. Therefore the Greenville Plateau cannot be the exhumed sub-Cretaceous peneplain; it must be younger.

There is no marked accordance of summits of the quartzite ridges in the Pine Mountain district. The only indication that these ridge tops might be remnants of an old, nearly peneplained erosion surface is the flat area on top of Indian Grave Mountain. However, this mountain is a topographically expressed anticline; therefore the flat area is probably structurally controlled.

Superposition of the Flint River

In flowing through the Warm Springs and Thomaston quadrangles, the Flint River crosses four quartzite ridges, cutting deep gorges. A more direct course is available to the river which would cross only one quartzite ridge. The course of the river through these ridges is not subsequent; there are no evident faults or other weaknesses in the rocks at the points of crossing. Therefore the Flint River must have been superposed onto the ridges.

Superposition could have been from a peneplain. However, there is a great difference in resistance to weathering between the quartzites and the schists and gneisses of this region. It is problematical that the areas underlain by quartzite could have been reduced to the same level as the surrounding areas; they probably would have formed monadnocks. Therefore superposition from a peneplain is doubtful.

White (1943) has described Cretaceous sediments north of the quartzite ridges in the Warm Springs quadrangle. The presence of these sediments shows that a sedimentary cover extended north of the ridges, but it does not furnish any evidence as to whether the sediments ever covered the ridges. The ridges may have remained as inliers projecting above the Cretaceous cover. However, Cretaceous or younger rocks may have completely covered the ridges, and the Flint River flowing across such a cover, could subsequently have been let down into its present position across the strike of the quartzites.

MINERAL RESOURCES

Introduction

The mineral resources of the Thomaston quadrangle include granite, quartzite, sand, gravel, kyanite, flake mica, sheet mica, graphite, and iron ore. Of these, granite, quartzite and sheet mica hold most promise for profitable exploitation at present. However, there is an ever changing and increasing demand for minerals, so that deposits of little value at present may be commercial in later years. For this reason, the writer has submitted a complete report upon the geology of this district in hopes that it may serve as a continuous guide to prospectors in the future.

The quartzite ridges of the western and northern parts of the quadrangle are characterized by great scenic beauty. It is recommended that much needed recreational facilities be established in these areas. The State could encourage, subsidize, or operate these facilities.

Mica

During time of peace the production of domestic sheet mica does not compete favorably with foreign mica. The price differential is so great that tariffs to protect and to promote domestic production are out of the question. During the time of war, however, it has been necessary to obtain a large amount of mica from domestic sources. During World War II the Federal Government subsidized domestic production by raising the price and allowing "up-grading". A large amount of mica was produced in the Thomaston district during this time. At the close of the war the subsidy was removed, thus production was halted. In the event of another similar emergency, mica will be mined again in the Thomaston district.

During the latter part of the nineteenth century India assumed leadership in production of mica, and has retained that leadership since then. It is not that the Indian deposits are richer, or more easily worked; they are no better than the deposits in the United States. The difference lies in the cost of labor. Indian labor in the past was so cheap that mica was produced and marketed at a price which captured the world market.

Mineralogically there are several species of mica. In the commercial sense, however, the term "mica" refers to muscovite. (Muscovite makes up over ninety-nine percent of commercial mica, and phlogopite less than one percent).

Muscovite is easily identified in the field. It occurs in flexible, elastic sheets which have one perfect cleavage. The color ranges through many shades of brown and green to colorless. The hardness is less than 3; it can be scratched with the fingernail.

Muscovite is a ubiquitous mineral. It occurs abundantly in igneous, sedimentary, and metamorphic rocks. In most places, however, the flakes are too small and too poorly concentrated for the deposit to be economic. The larger tabular crystals of muscovite, which are of commercial value, are recovered from pegmatites satellitic to granitic intrusions. The pegmatites generally occur marginal to the main mass of the granitic intrusion but in some cases occur within the body itself.

Beds in the Manchester schist are locally rich in muscovite which is suitable for grinding and use as a filler in rubber, etc. The commercial production of ground mica of this type would involve preliminary grinding and flotation; also, it would be necessary to select localities for development where not too much biotite mica occurs in the schist.

The pegmatites of this district were mined extensively shortly after World War One, and again during the last war, when mica production was subsidized by the government. Sheet mica in this district is flat, rum to ruby colored, free of spots, and of strategic quality. Before the close of the war, all sizes of India trim over an inch square sold for $8 per pound. Production ceased when the subsidy was removed at the close of the war, but mining has begun again recently because of encouragement by DMEA and DMPA.

Synthetic mica has been produced but as yet is still in the laboratory stage. One of the chief difficulties to be overcome is its production at a cost which can compete with that of natural mica.

A comprehensive study of the sheet mica mines and prospects of the Thomaston district was made shortly after the beginning of the war by Furcron and Teague (1943, pp. 19-48). Their detailed descriptions are quite complete.

Most of the properties were mined or prospected after their report was published, and these later notes are on file in the office of the State Geological Survey. Previous to the present work the mica-bearing pegmatites had not been correlated with any intrusive mass. During this study a granitic batholith was mapped and is here named the Jeff Davis granite. It was found that the mica-bearing pegmatites occur in a broad belt of migmatite around this batholith as well as in the batholith itself. Since the pegmatites are related in space to the Jeff Davis granite, they are also without doubt genetically related. This association of granite with pegmatite should be of value in further prospecting. Those areas within the schist-gneiss migmatite which are closest to the Jeff Davis granite will probably contain the largest number of pegmatites. It is here that commercial mica should be sought. (See Geologic map).

The areas of possible occurrence of economic mica deposits associated with the Jeff Davis granite are by no means restricted to the Thomaston quadrangle. The migmatite bordering the batholith on the north and south extends on to the east an unknown distance. It would be well if these areas to the east could be mapped geologically so that further prospecting can be guided by a broader knowledge of geologic occurrence.

Quarry Sites

Two large exposures of granite in Upson County would accommodate large scale quarrying operations.

Ten Acre Rock in the southern part of the county is a large exposure of garnet-biotite granite. The fabric and mineral composition of this rock is constant and the quarryman would be assured of a stone of unvarying quality. The red of the garnet and the black of the biotite give the rock a striking appearance. This granite has a strong lineation. Stone faced parallel to the lineation would have a linear texture, which could be used to great advantage by designers and builders. Stone faced perpendicular to the lineation would show no linear structure and would be massive in appearance. Stone from this locality could be used for monumental stone, building stone, trimming stone, and for road metal.

Large exposures of Jeff Davis granite are located on the M. M. McClellan property about six miles east of Thomaston. Stone from this locality has recently been crushed and used on county roads. Building and monumental stone could also be quarried at this locality.

Both these localities have the disadvantage of not being on a railroad. However, the McClellan property is on a good road and is not too far from the branch of the Central of Georgia Railroad which runs between Thomaston and Barnesville. It would not be too expensive to build a road to Ten Acre Rock because such a road would follow the crest of a ridge; there would be a few grades and no streams to cross. Due to transportation difficulties, both these localities are perhaps economic for road metal alone. If they were developed for road metal, a great amount of monumental and building stone could be quarried for use in the surrounding area, and the quarrying of trimming stone for shipment by truck to the railroad would then possibly be economic.

Road metal could also be obtained from the thin-bedded quartzites. This rock is a very porous flexible sandstone. On quarrying it breaks up into sand and gravel sizes. Locally this material is referred to as "rotten rock". Improved roads topped with such porous material drain well and are good even after long periods of rain.

In Upson County thin-bedded quartzite has been quarried along State Route 74 just east of Barker Springs. In Talbot County extensive exposures of thin-bedded quartzite occur at the top of Oak Mountain north of Pleasant Hill. At this locality the soil has been stripped off over a large area for use on roads. Therefore, quarrying operations could be begun without the expense of stripping off the overburden. Good flagstone and building stone would probably be a by-product of such an operation. The geologic map should be used in prospecting for these materials.

Graphite

Graphite is one of the most widely distributed minerals found in nature. It is a common constituent of igneous, sedimentary, and metamorphic rocks. The vast majority of these occurrences, however, are far below the margin of economic exploitation.

High production costs and the generally low grade of deposits have long been a deferrent to development of domestic graphite. During World War I the prospect of diminishing imports spurred domestic production into a boom which lasted as long as the war lasted. Again during World War II the prospect of shortages brought new life to the industry; the Federal Government subsidized both prospecting and production. The post-war production history has been one of continued effort not only to survive, but to expand and compete in the world markets.

The physical and chemical properties of graphite are so characteristic that it can be identified readily in the field. Graphite occurs most commonly in earthy lumps or as minute flakes in foliated masses. It is so soft that it will rub off on one's fingers as a black metallic smear. Graphite is composed entirely of carbon and as a result is infusible. It is also insoluble in acids. The specific gravity is 2.1.

Graphite of strictly inorganic origin is found in granite and vein deposits. Most graphite, however, is of organic origin. Coal is commonly converted to graphite in the contact aureole of igneous intrusions. The graphite of the foliated metamorphic rocks (schists and gneisses) was probably derived from organic matter contained in the original sediments.

In 1949 domestic production of graphite was 5,213 tons valued at $475,264. The average price was $91 per ton. During this same year the United States imported 31,855 tons valued at $1,260,467. The value per ton of the imported material ranged from $9 to $16 per ton for amorphous graphite and from $200 to $300 for standard grades of flake graphite.

Within the Thomaston quadrangle graphite occurs at many places in the lower schist member of the Manchester formation. The schist for the most part is deeply weathered and outcrops are few. Therefore, the lateral extent of any one graphite zone is not determinable, and reserves cannot be calculated by surface work. In outcrop, graphite-rich layers are interbedded with muscovite-rich layers. The concentration of graphite and muscovite in some of the deposits approaches the margin for economic mining operations. However, in view of the generally low concentrations and the uncertainty of reserves, development of these deposits is not recommended. This does not mean that the writer holds no hope for the presence of economic deposits. There could possibly be extensive workable deposits in the area south and southwest of Crest. But development of these deposits should not be considered until adequate reserves have been determined by drilling or other types of prospecting.

Graphite was once mined on Hurricane Creek one mile south of Crest. Small buildings were erected, and a small amount of graphite was produced, but the venture was not successful.

Iron Ore

Limonite, a hydrous iron oxide, is the second most important ore of iron. It is ubiquitous in nature and is responsible for most of the brown colors seen in sedimentary rocks and in soils.

In northwestern Upson County in the vicinity of Crest, Pickard, and Brooks Mountain, cobbles and boulders of massive limonite occur in large quantities. Massive limonite is found also along faults in this area. One of the faults bounding Brooks Mountain crosses a road 1.3 miles northwest of Burkett School. In the road-cut a body of limonite about ten feet wide occupies the fault.

Individual specimens of this limonite are very high in iron. However, the deposits are so small that mining would be below the margin of economy. Such small deposits were economic in the past when transportation was costly and the steel industry of the country had not yet been developed. Small amounts of iron were produced for local use. Today, however, with modern mining methods, a few deposits of high concentration and great reserve furnish ore to the steel making centers at a cost far below that which can be met by most small producers.

Sand and Gravel Deposits

Economic mineral deposits generally result only after the valuable constituents have been concentrated by some geologic process. Sand and gravel are common but they are of economic value only after they have been concentrated by running water. Within the Thomaston quadrangle there are two general areas which are favorable for the accumulation of sand and gravel.

The first of these is along Flint River in the southern part of the quadrangle. The gradient of Flint River is steep in this area because it is passing through the Fall Zone. The stronger current is able to carry larger particles in suspension, which are later dropped out where the current slows; thus, sand deposits are deposited just downstream from shoals. These deposits are formed principally during time of flood. An example of this is a sand deposit on the north bank of the Flint River about one-half mile south of Snipes Shoals.

The second general area is the lowland surrounding quartzite ridges. Streams running off these ridges during time of heavy rains deposit first gravel near the ridges and then sand further away. Noteworthy gravel deposits are found on the west flank of Pine Woods Ridge about one-half mile west of Smith Academy, and also in the vicinity of Jones Settlement and McCrary Settlement in the northwest corner of the quadrangle. Sand deposits from the quartzite ridges can be seen along Ten Mile Creek.

Kyanite

A limited demand rather than a limited source at present precludes a large world production of kyanite. If new uses could be found, enormous reserves would be available to satisfy the new demand. The kyanite deposits of Georgia are definitely among the potential sources.

Though used in only small amounts, massive kyanite is essential to the economy of the United States; it was necessary to stockpile this material during World War II. The United States obtains its present supply from domestic sources, from India, and from Kenya Colony, British East Africa. The average price in 1949 was $50 per ton. In this year domestic production was 12,115 tons.

Kyanite is an aluminum silicate; its composition is the same as that of sillimanite and andalusite. It occurs generally in blades and has an irregularly distributed blue tint. The hardness is distinctive in that a knife blade will make a scratch when drawn parallel to the length of a crystal, but will not make a scratch when drawn at right angles to the length.

The most common occurrence of kyanite is in metamorphic rocks which have been derived from clay-rich sediments. Some kyanite, however, is found in high-temperature veins.

Within the Thomaston quadrangle kyanite occurs abundantly as crystals in the schists of the Manchester formation and in the schist-gneiss migmatite, which is but migmatized Manchester schist. High concentrations of kyanite can be seen in the schist-gneiss migmatite in the road cuts along Route 19 just north of the Goat Rock fault. These expousres are deeply weathered, and most of the kyanite has been altered completely to a white clay. Though weathered at the surface, fresh material should be encountered at but little depth. The kyanite should not be hard to free from the mica schist in which it is imbedded. Another advantage of these deposits is that they are located close to an excellent highway. The percentage of kyanite in these rocks is high enough to warrant prospecting if the demand for this type of kyanite increases.

Springs

Several large springs occur in the Thomaston area, some of which are known as warm springs and others as cold springs. For climatic reasons 66° F. has been selected as the temperature which separates the cold and warm springs.

The higher temperature of thermal springs may be produced by two different and unrelated geologic processes. First, the heat may be derived from molten rock, that has worked its way close to the surface. Second, the water may circulate deep into the earth, become heated, and be forced back to the surface before it has had time to cool down. This second process is responsible for the warm springs of the Wacoochee belt.

In order for deep circulation to be effected there must be a permeable reservoir rock which on the one hand outcrops at a relatively high elevation and which on the other extends to a depth of several thousand feet below the surface. The reservoir rock must then be tapped at this great depth by some sort of restricted passage back to a point on the surface of low elevation. Water collects in the area of high elevation and gradually works its way down into the reservoir rock. The water is slowly heated according to the geothermal gradient, which in this district is about 1° to every 100 feet. The hydrostatic pressure of the column of water in the reservoir rock then forces water from the base of the column back up through the restricted passage to the surface. The ascent is faster than the descent; the water has only a limited chance to cool down and thus issues at the surface as a warm spring.

Within the Wacoochee belt the Hollis quartzite and the quartzite member of the Manchester formation are reservoir rocks. Because of their resistance to weathering they crop out at high elevations. They also extend to great depths below the surface. The restricted passages back to the surface may be either zones of high permeability within the quartzite or high angle faults.

Hewett and Crickmay (1937) have made a thorough study of the warm springs of the Wacoochee belt. They described two such springs within the Thomaston quadrangle: Thundering Springs with a temperature of 74° and Barker Springs with a temperature of 73° to 74°.

Thundering Springs, now owned by the Boy Scouts of

America, has been all but destroyed by pranksters who wanted to test the strength of the once mighty giant. The flow was once so strong that it sounded sometimes like thunder. Visitors formerly threw rocks into it to see the spring throw them back. Finally, these rocks so choked the spring that now it is but a bubbling pool and of no particular value or interest.

Barker Springs has a flow large enough to be used as a supply for a swimming pool. The higher temperature of this water not only makes bathing very pleasant but also makes the first plunge less difficult.

Several cold springs issue from the quartzite at the southern end of Bull Trail Mountain. The principal ones, known as Willingham Spring and Partridge Spring, have large flows of water and would be suitable for development as resorts. At the present writing the springs are undeveloped.

Recreational Areas

The topography of Middle Georgia is generally rolling, and the relief is very subdued; therefore, those areas of greater relief are recognized locally for their scenic beauty. The quartzite ridges and the gorges that have been cut through them by Flint River are so unique in this part of the country that they offer possibilities for the development of public recreational areas.

There is, in fact, a great need for additional recreational facilities in this part of Georgia. The state parks of the seashore and of the North Georgia mountains are a days drive away and cannot be visited except during time of vacation. This section needs recreational areas which can be reached by a drive of an hour or two so that a visit does not require more than a day.

American political philosophy has long recognized the duty of the state to foster cultural projects, and the development of recreational facilities in many parts of the country has become an outstanding accomplishment of this policy. If the State of Georgia operated or subsidized a well-run recreational area in the Thomaston section, it probably would be profitable. The greatest benefit, however, would be in human values for those who experience a cultural development through facilities not available at present.

The area around Mose Mountain and Pine Woods Ridge is an excellent location for recreational parks. The scenery is magnificent for this part of the country. There are a number of streams that could be dammed to form lakes for swimming and fishing. This area is also well suited for horse-back riding and hiking. Although riding and hiking are not popular sports in this section at present, they could be popularized if first class facilities were available. At present the land is used only for timber; the establishment of parks here would, therefore, not interfere with its present utilization. The capital investment required to establish such park facilities would be at a minimum.

Of the undeveloped natural resources of the Thomaston quadrangle, the most promising are its potential recreational facilities. The scenic beauty of the quartzite ridges is unique. There is also a pressing need for park facilities in the same general area. The situation, therefore, seems ripe for some move by the State toward the acquisition of well-located mountain land which may be developed for recreational purposes according to the needs and desires of the people of the district.

GLOSSARY

An_{20}. "An" with a subscript denotes the "anorthite content" of plagioclase. For example, An_{20} means a composition equal to 20% anorthite and 80% albite.

Anhedral. Showing no crystal faces.

Allotriomorphic. A fabric term for a rock the grains of which show no crystal faces.

Aphanitic. Fine grained (less than 0.5 mm.). Grains too small to be distinguished with the unaided eye.

Argillaceous. Containing a significant amount of clay.

Arkose. A feldspathic sandstone.

Batholith. A large igneous intrusion that extends indefinitely downward. Forty square miles is generally regarded as the minimum areal outcrop.

Blastomylonite. A rock which has been mylonitized and recrystallized.

Breccia. A rock which has been fragmented; the fragments are angular.

Charnockite. A hypersthene granite.

Chevron fold. A fold with a sharp crest and straight limbs.

Comagmatic. Igneous and genetically related.

Conglomerate. A rock composed principally of water-worn pebbles and cobbles.

Consanguineous. Igneous and genetically related.

Corona. A zone composed of one mineral surrounding a grain of another mineral.

Crystalloblastic. Composed of grains which have grown by a process of solution and recrystallization during metamorphism.

Diorite. A phaneritic igneous rock composed essentially of andsesine and two-eights to four-eighths mafic mineral. Hornblende is the most common mafite.

Equigranular. All grains more or less the same size.

Exfoliation. The splitting of curved slabs off a rock by weathering action.

Exsolution. Solid state differentiation by which a single crystalline phase breaks up into two phases, one as a host and the other as many small, oriented, isolated grains.

Fabric. All textural and structural features of a rock.

Foliation. All planar structure in rocks except that produced by sedimentation.

Formation. A large persistant stratum possessing the same lithologic or faunal features.

Fs_{20}. "Fs" with a subscript denotes the "ferrosilite-content" of minerals of the enstatite-hypersthene series. For example, Fs_{20} means 20% ferrosilite ($FeSiO_3$) and 80% enstatite ($MgSiO_3$).

Gabbro. A phaneritic igneous rock composed essentially of calcic plagioclase and clinopyroxene.

Geomorphology. The study of the configuration of the earth's surface, and the interpretation of geologic events by use of land forms.

Geothermal gradient. The increase in temperature with depth.

Geothermal metamorphism Metamorphism due to the high temperature which obtains at depth.

Gneiss. A foliated rock in which there are layers of different composition. Also a lineated rock in which the lineation is due to an alignment of mineral grains.

Granite. A phaneritic igneous rock composed essentially of quartz, potassium feldspar, and smaller amounts of sodic plagioclase and a mafic mineral.

Granitization. The change of the composition of a rock to that of a granite by a process not involving a silicate melt.

Granoblastic. Equigranular as a result of recrystallization during metamorphism.

Granodiorite. A phaneritic igenous rock composed essentially of quartz, sodic plagioclase, potassium feldspar and a mafic mineral.

Granulite. A fine-grained, equigranular metamorphic rock exhibiting little or no structure.

Group. A stratigraphic unit consisting of two or more formations which have some significant characteristics in common.

Heteromorphic. Deviating from the usual form.

Hornfels. A fine-grained rock produced by isochemical, thermal metamorphism of a sediment.

Hydrothermal. Hot aqueous (liquid or vapor).

Injection gneiss. A layered rock produced by insinuation of granitic material between layers of a foliated or bedded rock.

Itacolumite. A flexible quartzite.

Kinetic metamorphism. A change brought about in a rock by stress.

Leucocratic. Unusually large ratio of light to dark minerals.

Leucogranite. Granite with less than one-eighth dark minerals.

Lineation. Any linear structure within a rock.

Lit-par-lit injection. Insinuation of granitic material between layers of a foliated or bedded rock.

Mafic. Ferromagnesian.

Member. A subdivision of a formation of distinct lithologic character.

Metamorphism. Those processes which cause transformation of one rock into another type with a different set of characteristics.

Metasediments. Metamorphic rocks which have been derived from sedimentary rocks.

Migmatite. A mixed rock formed by intrusion of granitic material or by collection of granitic material as generally concordant sheets within foliated or bedded rocks.

Mylonite. An extremely fine-grained, coherent rock produced by the grinding action along the plane of a thrust fault.

Norite. A phaneritic igneous rock composed of calcic plagioclase and orthopyroxene.

Paracrystalline. Contemporaneous to recrystallization.

Pegmatite. A very coarse-grained igneous rock or hydrothermal vein, generally of granitic composition. Individual grains in most cases are greater than one centimeter in diameter.

Peneplain. A land surface of very low relief formed by mass-wasting of the interfluves.

Petrography. Systematic description of rocks.

Phaneritic. Visibly crystalline.

Phenocryst. A large grain of a mineral surrounded by finer-grained minerals. Phenocrysts must be magmatic.

Pleochroism. The property of a substance whereby the color of transmitted light depends on the vibration direction of the transmitted rays.

Porphyroclast. A large relict grain of a mineral left after the surrounding grains have been reduced in size by mylonitization.

Porphyritic. Some grains appreciably larger than the others. The small grains form the continuum.

Postcrystalline. Subsequent to recrystallization.

Precrystalline. Preceding recrystallization.

Quaquaversal. Dipping outward in all directions.

Quartz monzonite. A phaneritic igneous rock composed essentially of quartz, potassium feldspar, sodic plagioclase and a mafic mineral.

Quartzite. A rock derived from a sandstone by isochemical metamorphism.

Radiohalo. A zone of discoloration surrounding a radioactive mineral.

Recrystallization. A metamorphic process of solution and redeposition by which new mineral grains are formed at the expense of older mineral grains.

Rosiwal analysis. A statistical determination of the relative abundance of the minerals in a rock.

Schist. A visibly crystalline, strongly foliated rock in which all folia are alike.

Schistosity. A foliation in a phaneritic rock in which all layers are alike.

S-plane. Any planar structure in a rock.

Subhedral. Showing some crystal faces.

Subsilicic. Relatively low silicia content. "Basic".

Superposed stream. A stream which has been let down onto a terrane of older rocks from an unconformably overlying cover.

Synantetic. Formed between two minerals as a reaction between these minerals.

Ultramafic. Composed entirely of ferromagnesian minerals.

Ultramylonite. An extremely fine-grained, coherent rock produced by complete reduction of all mineral grains of a rock by the grinding action along the plane of a thrust fault.

Vermicular. Worm-like.

Window. A terrane which was originally overlain by an overthrust block, but which has been exposed by subsequent erosion through the thrust plate. A window is completely surrounded by overthrust rocks.

Xenolith. A fragment of the country rock (wall rock) which has been included in an igneous rock.

Zone of distributive movement. A zone in which the rocks have been deformed by differential movement.

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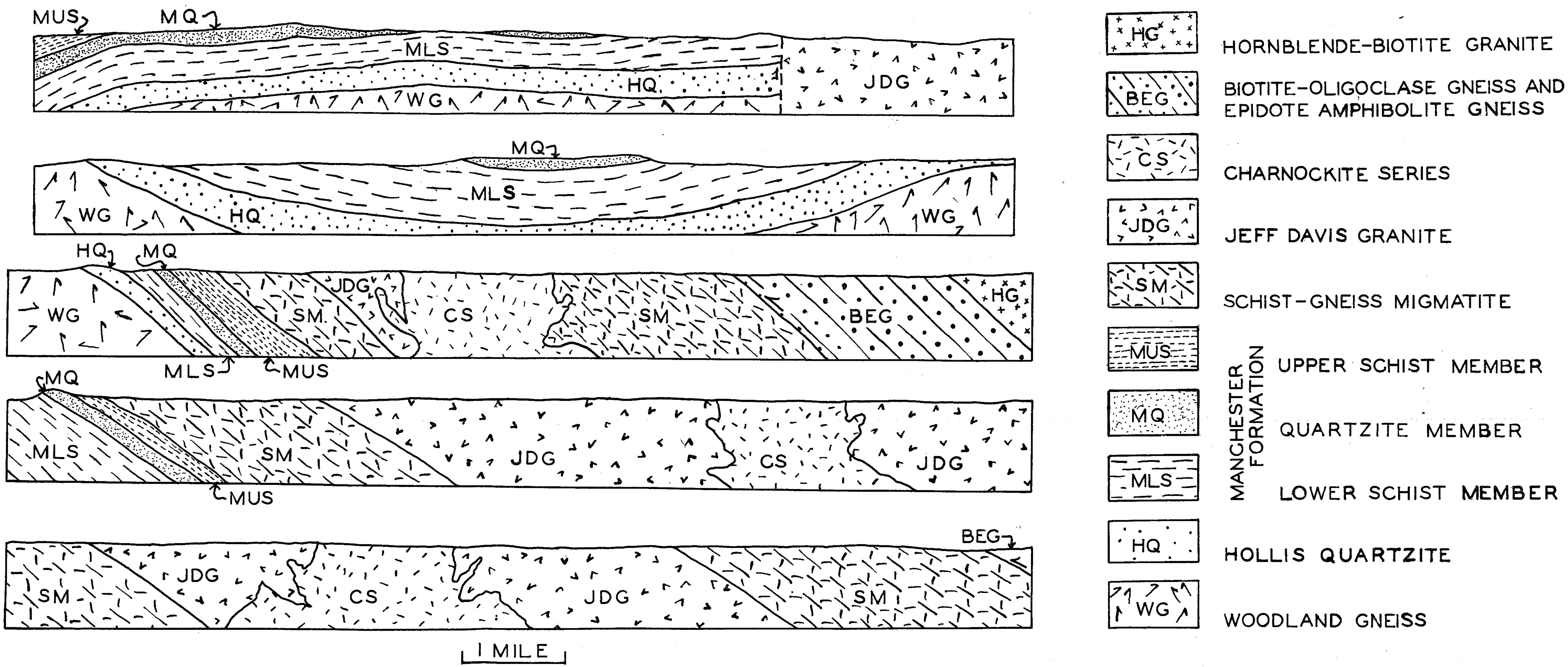
PLATE II

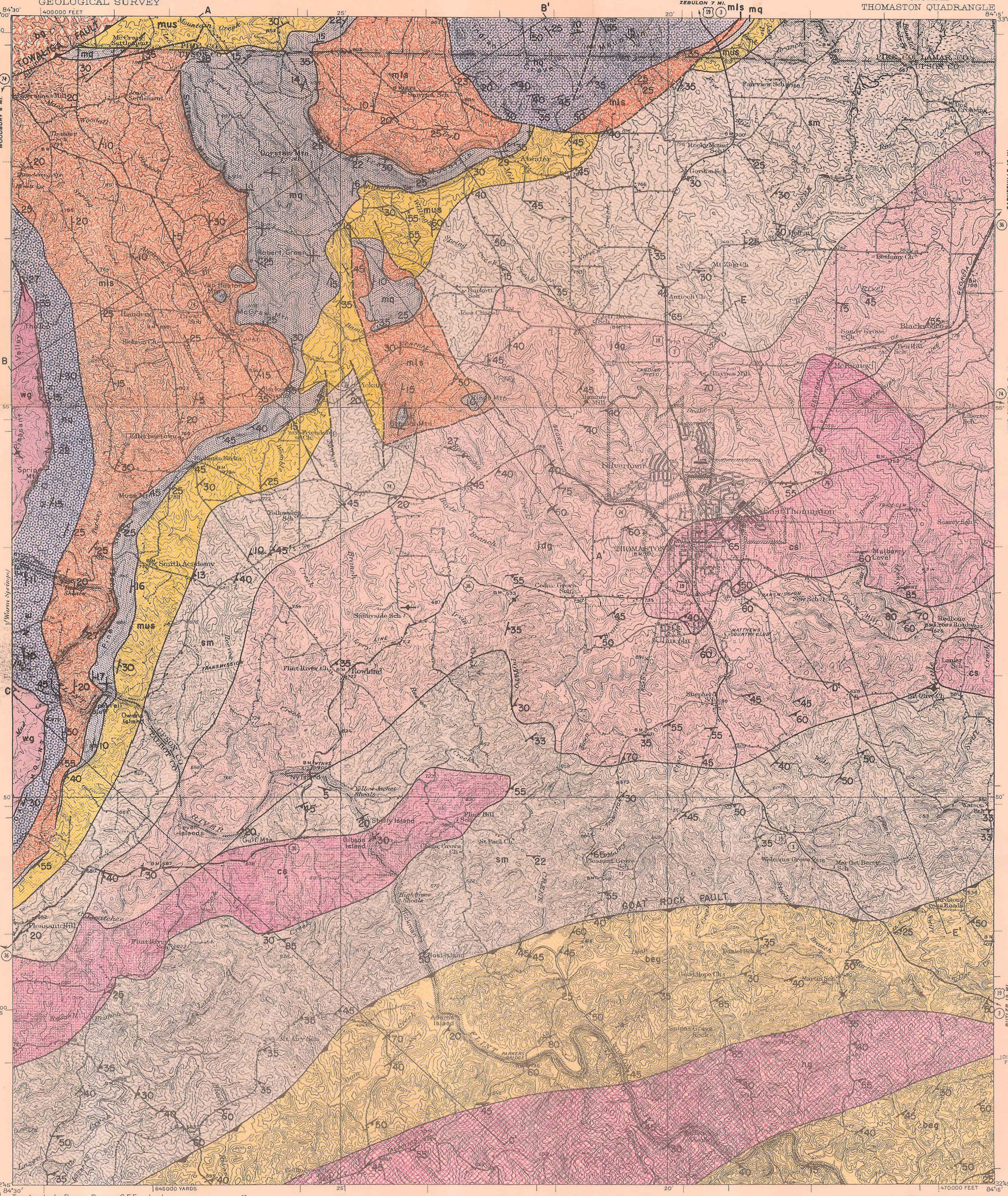


STRUCTURE SECTIONS GEOLOGIC MAP OF THOMASTON QUADRANGLE, GEORGIA CROSS SECTIONS TO ACCOMPANY PLATE III

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

DEPARTMENT OF MINES, MINING AND GEOLOGY
GARLAND PEYTON, DIRECTOR

GEORGIA
THOMASTON QUADRANGLE



EXPLANATION

NORTH OF TOWALIGA FAULT

bg — Biotite gneiss

BETWEEN TOWALIGA FAULT AND GOAT ROCK FAULT

cs — Charnockite series

sm — Schist-gneiss migmatite

jdg — Jeff Davis granite

mus / mq / mls — Manchester formation (includes a lower schist member, a quartzite member, and an upper schist member)

hq — Hollis quartzite

wg — Woodland gneiss

PRECAMBRIAN (?)

SOUTH OF THE GOAT ROCK FAULT

hg — Hornblende-biotite granite

beg — Biotite-oligoclase gneiss and epidote amphibolite gneiss

20 — Strike and dip of bedding

30 — Strike and dip of foliation and schistosity

Fault

Thrust fault

Topography by Roscoe Reeves, C.F. Fuechsel, C.S. Maltby, J.L. Farmer, E.C. Gartner, J.L. Cram, and J.M. Johnson
Surveyed in 1934-1935

Geology by James W. Clarke

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 1935

GEOLOGIC MAP OF THOMASTON QUADRANGLE, GEORGIA

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles
5000 0 5000 10000 15000 20000 Feet
1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet
Datum is mean sea level

ROUTES USUALLY TRAVELED
HARD IMPERVIOUS SURFACES
OTHER SURFACE IMPROVEMENTS
1943
U. S. ROUTE
STATE ROUTE

Polyconic projection. 1927 North American datum
5000 yard grid based on U.S. zone system, B
10000 foot grid based on Georgia (West) rectangular coordinate system

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