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STATE DIVISION OF CONSERVATION

DEPARTMENT OF MINES, MINING AND GEOLOGY

GARLAND PEYTON, Director

THE GEOLOGICAL SURVEY

Bulletin Number 67

THE GEOLOGY OF HART COUNTY, GEORGIA

by

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ATLANTA
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ABSTRACT

GEOLOGY OF HART COUNTY, GEORGIA

Hart County is in northeastern Georgia, where the Seneca and Tugaloo Rivers join to form Savannah River.

The area is topographically mature and the rocks are deeply weathered.

Most of the rocks are either metasedimentary schists and gneisses or granitic rocks. Feldspathic amphibolite gneiss of uncertain origin also appears. The rocks are mainly in the amphibolite facies, although some retrograde assemblages occur.

The metasedimentary rocks include biotite-plagioclase gneisses, sillimanite-graphite schists, sillimanite-mica schists and gneisses, and staurolite-mica schists. Two varieties of granitic rocks occur: a biotite granodiorite gneiss and a slightly foliated to massive muscovite and/or biotite granodiorite. The latter rocks contain many textural variations such as pegmatitic, porphyroblastic and graphic types. Between the biotite granodiorite gneiss and the metasedimentary rocks, there is a wide contact zone containing a mixture of granite and country rock.

The structural development is divided into two periods. The earlier is characterized by folding of variable intensity. From south to north the trend of the fold axes changes from N2OE to NW. The later period is characterized by a northeasterly trending shear zone. Structural features connected with this period are crossfolding, cleavage, small faults and in thin sections cataclasis. Metamorphic effects are confined to the choritization of biotite.

A systematic statistical relation exists between lineation and jointing. Changes in the strike of one structure is accompanied by a sympathetic change in the other.

Microscopic studies show that metamorphism was accomplished in three overlapping phases; regional metamorphism, contact metamorphism and kinetic metamorphism. Metasomatism also occurs.

The evidence favors the idea that the biotite granodiorite gneiss was formed by metasomatic processes. The muscovite and biotite granodiorites may have formed by anatexis of the biotite granodiorite gneiss.

Atlanta, Feb. 7, 1958

To His Excellency, Marvin Griffin, Governor
Commissioner Ex-Officio
State Division of Conservation

Dear Governor Griffin:

I have the honor to submit herewith Georgia Geological Survey Bulletin No. 67, "The Geology of Hart County, Georgia," by Willard H. Grant. This investigation was undertaken by Dr. Grant as a thesis problem for the degree of Doctor of Philosophy at The Johns Hopkins University. The project was sponsored by the Georgia Geological Survey.

Previous investigations by this survey have indicated the presence of extensive deposits of sillimanite in Hart County which is an important undeveloped resource; also our investigations have discovered and described sheet mica and deposits of mica suitable for grinding purposes. The present report represents a complete investigation of these and other mineral resources of the county.

The detailed geologic map accompanied by the text of the report will serve as a base for later geological investigations of many types. This type of map affords an excellent base for complete ground water and surface water investigations as well as for the discovery of new mineral resources.

Very respectfully yours,

Garland Peyton
Director

ILLUSTRATIONS

PLATES

Plate

LIST OF TABLES

ACKNOWLEDGMENTS

The writer is indebted to Dr. E. Cloos and Dr. A. C. Waters of the Johns Hopkins University for much assistance and many valuable suggestions in preparing this report. The subject was suggested by Dr. A. S. Furcron of the Georgia Geological Survey who visited the writer in the field and made numerous useful suggestions. Expenses for the field work which extended over a nine month period, were supplied by the Georgia Geological Survey.

The writer also expresses his appreciation to the Funkhouser Company for their courteous cooperation.

INTRODUCTION

Hart County lies in the upper Savannah River valley of northeastern Georgia, Figure 1. Most of the county is between 34°15′ and 34°30′ north latitude, and 82°50′ and 83°05′ west longitude.

The problem involved mapping of metamorphic and granitic rocks, determination of their mineral and in some cases chemical compositions, and measurement and interpretation of their structural features. Interpretations are advanced on the origin of the granitic rocks, the effects of metamorphism, and the structural development. Weathering and geomorphology are treated briefly.

The area was mapped in the summer of 1950 and the summer and fall of 1951, and took approximately nine months.

The county road map, prepared by the Georgia State Highway Board at a scale of two inches to one mile, was used as a base map.

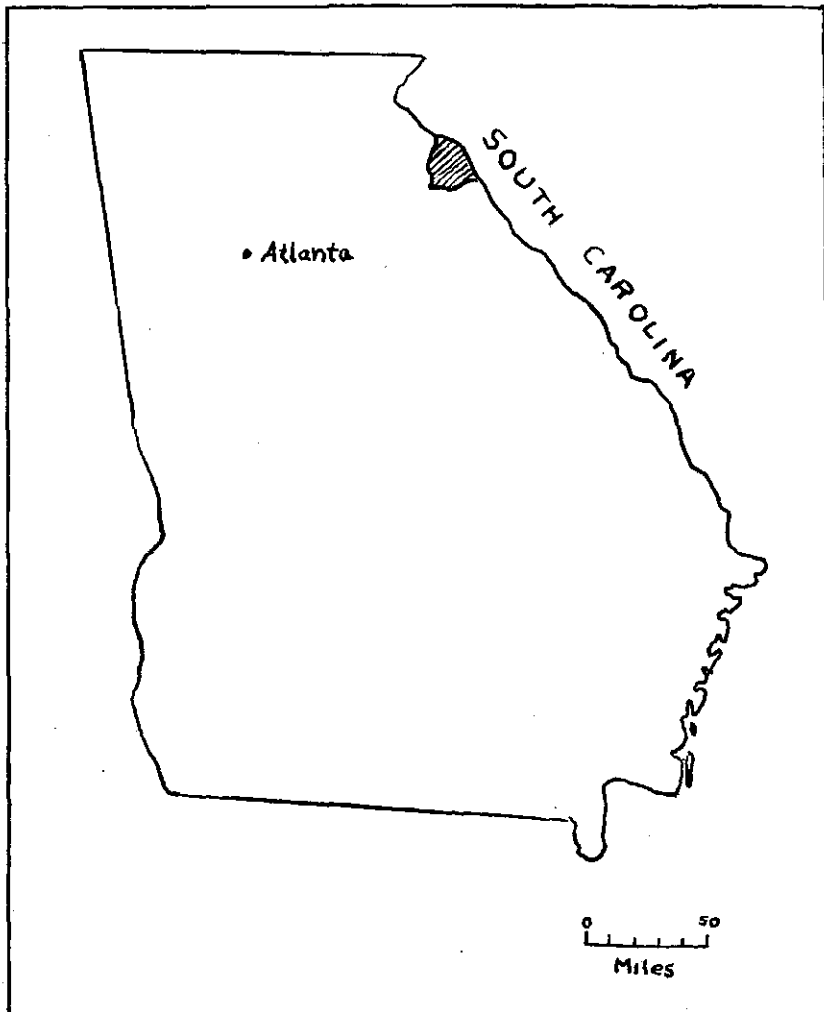

Figure 1.—Index map of Georgia showing the location of Hart County.

Geomorphology

Regional Description

According to LaForge (1925) Hart County lies in Midland Georgia. This larger unit has two divisions, the Midland Slope, and the Washington Plateau. The location of these divisions is shown in Figure 2. LaForge (1925, p. 84) described the Washington Plateau as a nearly smooth upland whose surface descends gently southeastward. It is trenched by many stream valleys and broken by a few residual knobs and ridges. LaForge (1925, p. 82) described the Midland Slope as a smoothly sloping surface with stream valleys and a few residual mountains which are only steep hills. The streams have generally steeper gradients than those of the Washington Plateau.

Local Description

Topographic maturity is indicated by low, broad drainage divides. The interior of the county is a gently rolling upland with broad shallow stream valleys. Along the major rivers and to a less extent the larger creeks, this upland is deeply

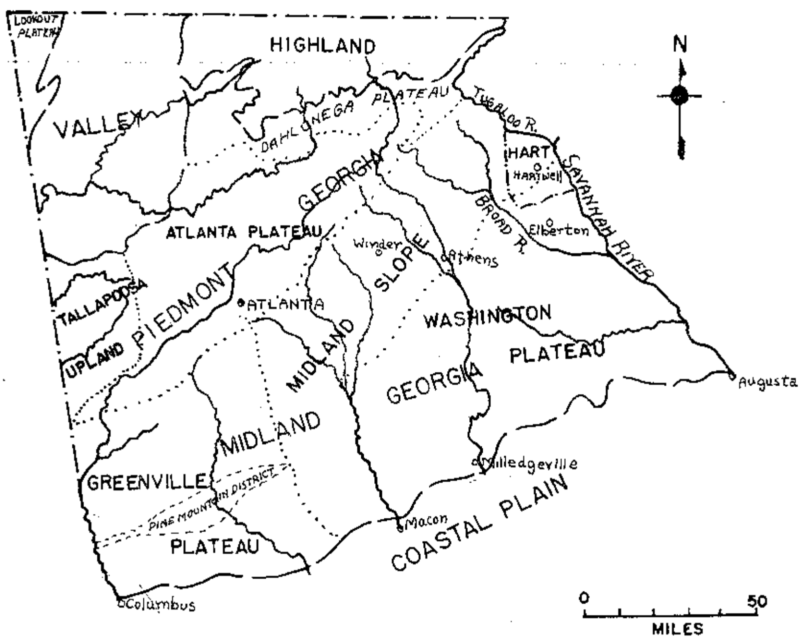

Figure 2.—The topographic divisions of the Central Upland, after LaForge.

intrenched producing a rugged topography. The intrenched area, underlain by biotite granodiorite gneiss in the Shoal Creek District, differs from areas underlain by the metasedimentary schists and gneisses in having dome-shaped hills instead of elongate ridges. A similar area in Smith District shows only a weak tendency toward domed hills which is manifested by a local radial drainage pattern.

Stream patterns are dominantly dendritic and rarely radial. The southeasterly trend of stream courses is thought to be partially controlled by the structure of the underlying rocks.

Climate

The essential characteristics of the climate are summarized in the following data taken from the U. S. Department of Agriculture Yearbook for 1941.

Temperature:

Length of record	38 years
January average	44.1°F
July average	79.8°F
Maximum	109°F
Minimum	3°F

Figure 3.—Graph showing the average monthly precipitation over a 38-year period. (data from U.S.D.A. Yearbook 1941.)

Killing frosts:

Length of record	38 years
Average, last in spring	April 2
Average, first in fall	Nov. 2

Rainfall:

Figure 3 shows graphically the average monthly precipitation over a 38 year period.

Weathering

General Statement

The term saprolite was coined by G. F. Becker (1895, p. 289) as a general name for decomposed, earthy, but untransported rock. It is used in this sense herein, but also implies the retention of foliation and other preexisting structures.

The results of weathering dominate the landscape. Fresh rock is confined to stream and artificial cuts. Saprolite is common at the surface and sometimes extends to depths greater than 100 feet.

Weathering Agents

Commonly recognized agents causing physical disintegration of rocks are ice, plants and animals. Ice breaks up rock in two ways. Water confined in a crack will, upon freezing, expand about nine per cent, thus splitting the rock. Alternate freezing and thawing can cause considerable rock breakage. Growing columnar ice crystals have been observed breaking up saprolite. According to Taber (1929, p. 443) ice columns develop at the surface of moist clay soils when the temperature of the ground immediately below the surface remains above freezing while the temperature of the air is below freezing.

Chemical agents in rock decomposition are water, carbonic acid, humic and other organic acids, clay acid and oxygen. The comparative ease with which various rocks decompose is shown in Figure 4. Each lithologic type is represented by a "pie slice". The longer the "pie slice" before being cut off by a straight line the greater its susceptibility to chemical weathering. Below the straight line the usual color of the B soil horizon is given. Many different rock types give rise to similar appearing B horizons. However, Jenny (1941, p. 78) points out that soils which appear uniform on casual inspection may reveal wide fluctuations if subjected to chemical analysis.

Table I is a list of minerals which commonly occur in the soils. The iron coating noted in the fourth column seems to result from weathering and is found frequently on minerals which do not contain iron.

Table I—The Occurrence of Minerals in Soil.

Mineral	Unaltered	Altered	Acquires Fe-coating	Remarks
Quartz	+		+	
Staurolite	+			Crystals pitted and dull
Tourmaline	+?		+	Crumbly, has yellow clay in fractures
Sillimanite	+		+	Forms clay in very wet places
Hornblende	rare	+		
Biotite		+		Persistent bronze flakes
Muscovite	+?			Appears to lose elasticity
Garnet		+partial		Usually has thick limonite coat
Feldspar		+		Usually pseudomorphs of kaolin
Graphite	+			

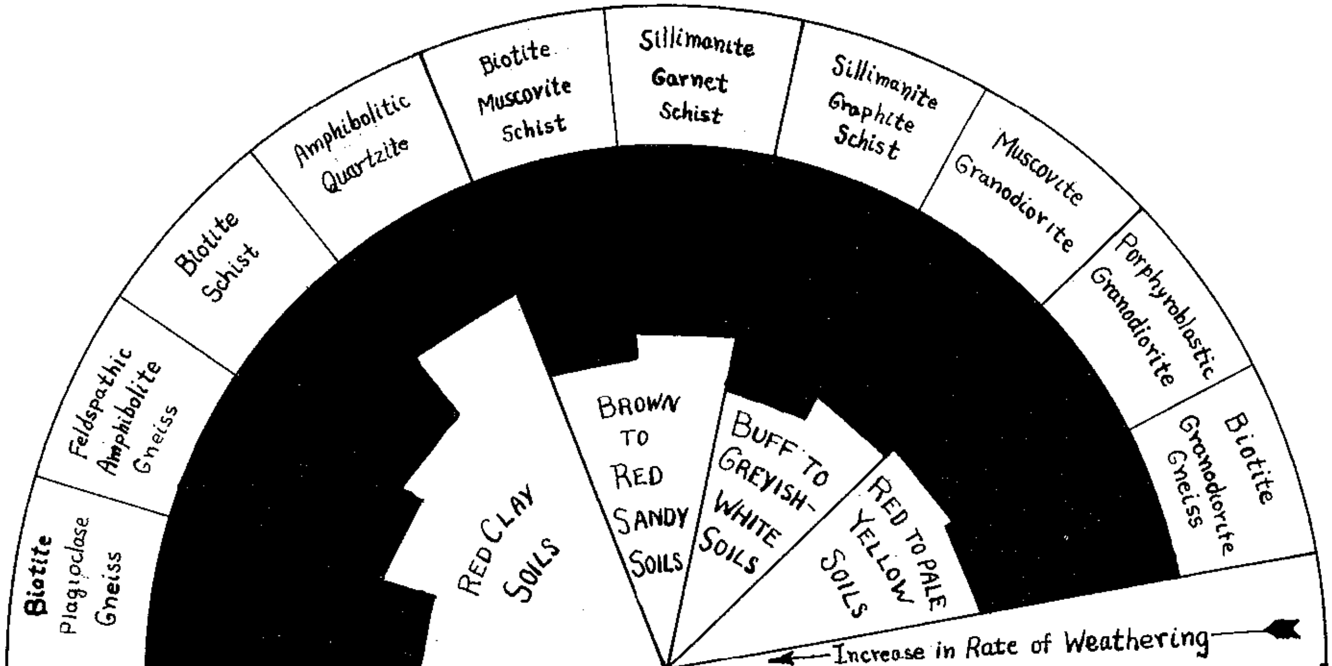

Figure 4.—Diagram showing the relative rates of weathering on various rocks and the usual color of the subsoil.

PETROGRAPHY

Metasedimentary Rocks

General Statement

The data included here concerns only those rocks that appear at the surface. Hence they are a select group, and do not represent all. The rocks that occur at depth surely include additional variations in mineralogy.

Rocks whose volume percentages are given represent an even more select group because they are fresh or only slightly weathered. Probably they are higher in quartz and lower in plagioclase than the typical rock.

One hundred and twenty thin sections and twenty sawed slabs were examined.

Optical data on the minerals is found in Table XIII.

Four specimens were chemically analyzed by Dr. L. H. Turner, Chemist for the Georgia Geological Survey.

Staurolite-mica schist.

Field description. The typical schist has a silver grey ground mass composed of millimeter-size grains of muscovite and biotite. Porphyroblasts of staurolite, ranging up to 3 by 1 cm, and occasionally garnet, ranging up to 4 mm, are scattered through the ground mass. Most of the staurolite is in single crystals but a few 60° twins occur. The chief variation in the schist is the amount of quartz which locally forms layers of micaceous quartzite. Pegmatites and quartz-veins are quite scarce.

Staurolite has been altered to chlorite near the contact with granite in the northeastern part of the area mapped as staurolite-mica schist.

Outcrops of fresh rock are rare and saprolite is only a little more abundant. Staurolite crystals occur in considerable abundance in the soil and reveal the distribution of the staurolite-mica schist.

Microscopic description. The grain size of the schist is about 1 mm. Staurolite crystals range up to 8 mm. and usually contain scattered inclusions of quartz and opaque dust, Figure 5. Xenoblastic quartz grains include tiny spicules which may be sillimanite. Muscovite and biotite occur in several generations which have suffered variable amounts of deformation. The biotite has a red brown pleochroism and includes zircons with pleochroic halos. Garnet idioblasts may slightly distort the surrounding mica. A small quantity of feldspar is also found.

The altered schist is the same as the normal schist except for the replacement of staurolite by daphnite and some of the biotite by penninite. Table II contains Rosiwal analyses of the normal schist and the altered schist.

Table II—Modal Analyses of Staurolite and Chlorite Schists.

	A		*B*
Biotite	22	Chlorite	18
Muscovite	20	Muscovite	23
Quartz	34	Quartz	49
Staurolite	20	Garnet	7
Sillimanite (fibrolite)?	3	Opaque	1
Feldspar	1	Biotite	}
Opaque Matter	Tr	Feldspar	}
Zircon	Tr	Sillimanite (fibrolite)?	} 2
	—	Tourmaline	}
		Staurolite	}
		Zircon	Tr
			—

A. Staurolite schist from a road cut 0.6 miles northwest of Bethany Church. The biotites are red brown and the plagioclase is about Ab_8An_2.

B. Chlorite schist from a gulley 0.8 miles due south of Flat Shoals Church.

Sillimanite-mica schists and gneisses

Field description. The typical rocks are dark grey even-grained schists with grain sizes ranging from 1 to 3 mm. They are composed of quartz, biotite, muscovite, sillimanite and/or garnet. Fibrolite, a fibrous variety of sillimanite, occurs in elongate or contorted streaks and small pods resembling deformed pebbles in a conglomerate. Sillimanite also occurs in match stick-shaped idioblasts randomly oriented on foliation planes. Megascopic sillimanite may be absent. These characteristics superficially modify the appearance of the rock. Rocks containing sillimanite idioblasts occur in a zone shown on Plate I. Red-brown almandine is the most common garnet but pinkish-violet rhodalite occurs in the flaggy schists near New Prospect Church. Most specimens contain abundant

Figure 5.—Staurolite crystal and folded mica in staurolite-mica schist. Crossed nicols 35 X. Rock from road cut 0.6 miles northwest of Bethany Church.

quartz, but in the southern part of the county small outcrops of sillimanite-garnet-biotite schist occur. Weathered rocks have a dark red-brown color.

Layers of amphibolitic quartzite, granite, pegmatite, sillimanite-graphite schist and biotite-plagioclase gneiss occur sporadically in the sillimanite-mica schists. The area west of Hartwell, contains muscovite schists associated with muscovite-rich sillimanite-graphite schist and the typical sillimanite-mica schist.

Microscopic description. The common texture is schistose. Figure 6 is a photomicrograph of a typical thin section. Quartz grains have an irregular outline. Sillimanite varies in its development from fuzzy, contorted, fibrous masses (fibrolite) to well formed idioblasts, Figure 7. Garnet in a quartz-rich matrix is usually fractured but in a mica-rich matrix it is not. Biotite has a red-brown pleochroism and shows more distortion and shredding than muscovite. Minor minerals are zircon, graphite, tourmaline and oligoclase.

Rosiwal analyses of several specimens of sillimanite-mica schist are given in Table III.

Origin. A sedimentary origin is suggested by the variety of rocks interlaminated with the sillimanite-mica schist. Furcron and Teague (1945, p. 15) regard these rocks as metamorphosed aluminous clay beds. Osborn (1936, p. 205) concluded that the sillimanite gneisses of the Grenville series which are similar to those described, were derived from aluminous sedimentary rocks.

Table III—Modal Analyses of Sillimanite-mica Schists.

	A	B	C	D	E
Biotite	22	14	20	30	34
Muscovite	13	16	5	10	18
Quartz	61	64	65	37	46
Sillimanite	4	5	2	21	Tr
Plagioclase*	1	----	1	Tr	Tr
Garnet	----	----	7	----	----
Tourmaline	----	Tr	----	----	----
Zircon	Tr	Tr	Tr	Tr	Tr
Opaque**	Tr	Tr	Tr	1	2

*Plagioclase is probably oligoclase.

**Opaque material is graphite and iron oxides.

A. Sillimanite-mica schist from a stream cut 1.4 miles northwest of Vanna near the Madison County line.

B. Garnet-sillimanite-mica schist from the west side of the stream about 2.1 miles southeast of New Prospect Church. Biotite is red brown and sillimanite is the fibrolite variety.

C. Fine grained grey sillimanite-mica gneiss from a road cut 0.2 miles northeast of Bio Church. The biotite is red brown.

D. Sillimanite-mica schist from a road cut on Georgia highway 8, 1.3 miles east of Nancy Hart Memorial. Red brown biotite and the sillimanite is in large (2 mm. by 15 mm.) crystals.

E. Sillimanite-mica schist from the mixed rock zone taken about 0.2 miles upstream from the mouth of Powderbag Creek.

Sillimanite-graphite schist

Field description. This rock is known entirely from strongly foliated saprolite exposures. Locally it contains thin layers of biotite-garnet schist, biotite schist, biotite-plagioclase gneiss and minor amounts of amphibolitic quartzitic, spessartite-quartz rock and granite. The sillimanite-graphite schist is best exposed in the Bowersville area where there is an upper horizon which contains limonitic layers, (possibly derived from pyrite) and a lower part without limonite. In other parts of the county the two horizons cannot be recognized with certainty. The schist south and west of Hartwell is muscovite rich and appears to pass locally into muscovite schist. Scattered narrow lenticles of sillimanite-graphite schist occur

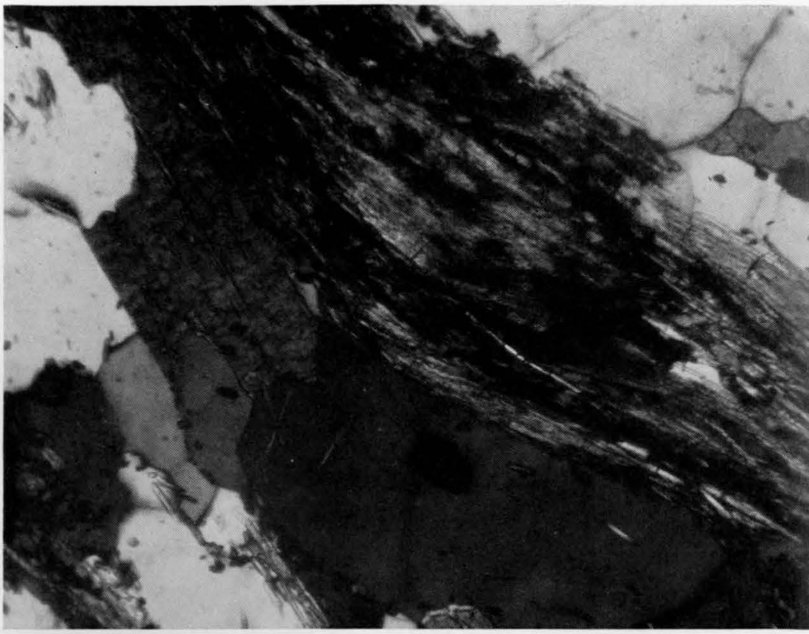

Figure 6.—Sillimanite (fibrolite) in a sillimanite-mica schist. Crossed nicols. 100 X. Rock from a creek outcrop 0.85 mile S47E of the intersection of Georgia highway 172 and North Beaverdam Creek.

Figure 7.—Sillimanite idioblasts in sillimanite-mica schist. Crossed nicols. 35X. Rock from field outcrop 1.75 miles S25W of Bio Church.

in the sillimanite-mica schist in a southwesterly trending zone from near Bio Church to North Beaverdam Creek.

The least weathered specimen is a fine grained, intensely foliated, fibrous-looking, yellowish-white schist. Megascopic minerals are sillimanite, quartz, muscovite and a scattering of graphite. Tourmaline occurs locally.

Muscovite schist from the Hartwell area is silver-grey and the muscovite crystals have been smeared together producing a satin-like luster on the foliation planes. It also contains quartz and rarely tourmaline.

Microscopic description. The Bowersville rock has a cataclastic texture, Figure 8. The principal minerals are sillimanite, (small crystals and fibrolite), muscovite, biotite and quartz. The grain size ranges from dust-size particles to 1.5 mm. Some post-movement recrystallization is indicated by muscovite and quartz porphyroblasts crossing the old foliation plane which is marked by minute graphite inclusions.

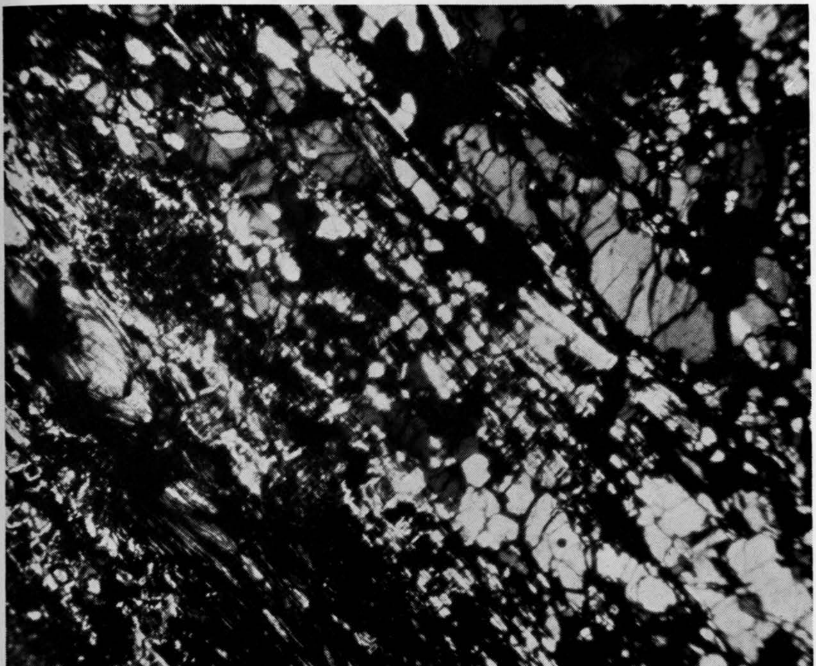

Figure 8.—Cataclastic texture in sillimanite-graphite schist. Crossed nicols 32X. Rock from road cut 0.25 miles north of the intersection of Georgia highways 51 and 17.

Figure 9 is a sketch drawn from a thin section of muscovite schist from the Hartwell area. It contains patches of rock similar to the sillimanite-graphite schist.

The black areas in Figures 8 and 9 are largely due to iron oxides formed by weathering.

Origin. The field work suggests that the sillimanite-graphite schist is a cataclastic facies of the sillimanite-mica schist. However, the difference may be due to an original lithologic difference or to metamorphic differentiation, as well as cataclasis. The poor preservation of the rock makes any conclusion uncertain.

The muscovite schists are probably the result of metasomatism of the sillimanite-graphite schist. This conclusion is supported by the presence of relic fragments of sillimanite-graphite schist in the muscovite schist and its restriction to areas where much muscovite granodiorite occurs.

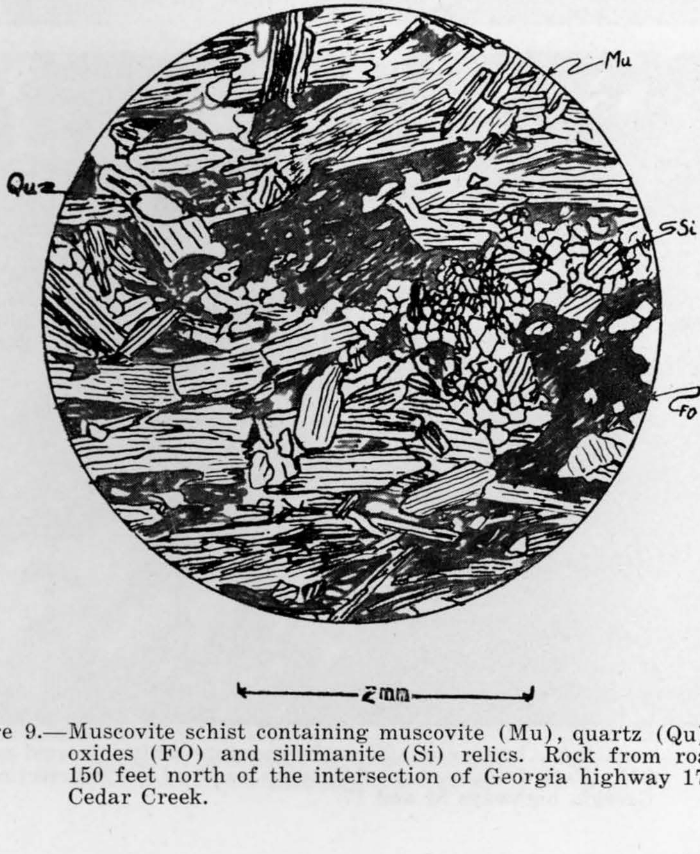

Figure 9.—Muscovite schist containing muscovite (Mu), quartz (Qu), iron oxides (FO) and sillimanite (Si) relics. Rock from road cut 150 feet north of the intersection of Georgia highway 171 and Cedar Creek.

Amphibolitic quartzites

Field description. These rocks occur as scattered lenticles and stringers interlaminated with all of the metasediments except the staurolite-mica schist. The quartzites commonly range from two to six inches and rarely up to two feet in thickness.

The superior weathering resistance of the quartzite is shown by the occurrence of brownish-yellow clay encrusted blocks with cores of fresh rock enclosed in a completely decomposed matrix. Sometimes layers of quartzite can be traced by float over distances up to one and one-half miles. This feature makes the quartzites helpful in solving local structural problems.

An interesting amphibolitic quartzite occurs in the biotite granodiorite gneiss. It is exposed in a road cut 0.7 miles west of Cokesbury Church. A collection of specimens, both float and in place shows a nearly complete gradation between the quartzite and the granodiorite gneiss.

The typical quartzite is even textured, greyish-white to black rock with an average grain-size less than 1 mm. Quartz, garnet and amphibole can be distinguished with a hand lens. Some specimens show, on fresh surfaces, a weak compositional banding which resembles bedding.

Table IV—Modal Analyses of Amphibolitic Quartzites

	A	B	C	D	Chemical Analysis D	
Hornblende	24	17	2	5	SiO_2	68.00
Plagioclase	20	12	5	22	Al_2O_3	13.44
Quartz	52	56	84	50	Fe_2O_3	1.24
Pyroxene	----	----	----	15	FeO	3.73
Garnet	2	--	4	22	MnO	Tr
Titanite	1	2	1	2	MgO	2.21
Epidote*	Tr	12	2	5	CaO	7.25
Zircon	----	Tr	----	...	Na_2O	1.69
Calcite	----	----	2	Tr	K_2O	0.58
Muscovite	----	----	Tr	...	TiO_2	0.23
Apatite	Tr	----	Tr	Tr	SO_3	1.42
Opaque Minerals**	Tr	1	----	Tr	P_2O_5	0.03
					Loss on ignition	0.45
						100.27

*includes clinozoisite. L. H. Turner, Analyst

**includes sulfides and oxides, pyrite, magnetite, hematite and leucoxene.

A. From a saprolite in a road cut on U. S. 29, 0.8 miles east of Oak Bower Church. Associated with granitic materials, biotite-plagioclase gneiss and sillimanite-mica schist. The plagioclase is An_{60}.

B. From the east bank of Morea Creek 1.4 miles southeast of Goldmine. It was in contact with the biotite granite. The plagioclase is approximately An_5.

C. From the mixed rock zone 1.2 miles west of Hatton's Ford in the Tugaloo River. The plagioclase is saussuritized. The hornblende includes a minor amount of anthophyllite.

D. From a road cut 1.6 miles northwest of Hartwell. Associated with quartzose sillimanite mica schists and some granitic material. Plagioclase is An_{65}.

Microscopic description. Textures vary from granoblastic to granitoid. Grain size range from less than 0.1 to 0.5 mm. but hornblende and quartz may be up to 4 mm. The major minerals are quartz, plagioclase and hornblende, but locally diopsidic pyroxene and epidote may be abundant. Saussuritization and sericitization of plagioclase occurs. Plagioclase is generally untwinned. Its composition ranges from An_{70} to An_{40}, most grains fall between An_{65} and An_{55}. The common amphibole is pale green hornblende but a little anthophyllite and a fibrous green amphibole have been noted. Minor constituents are titanite which occurs in all specimens, and occasional traces of scapolite, siderite, calcite, zircon, ilmenite leucoxene, chlorite, biotite, muscovite, pyrite and magnetite.

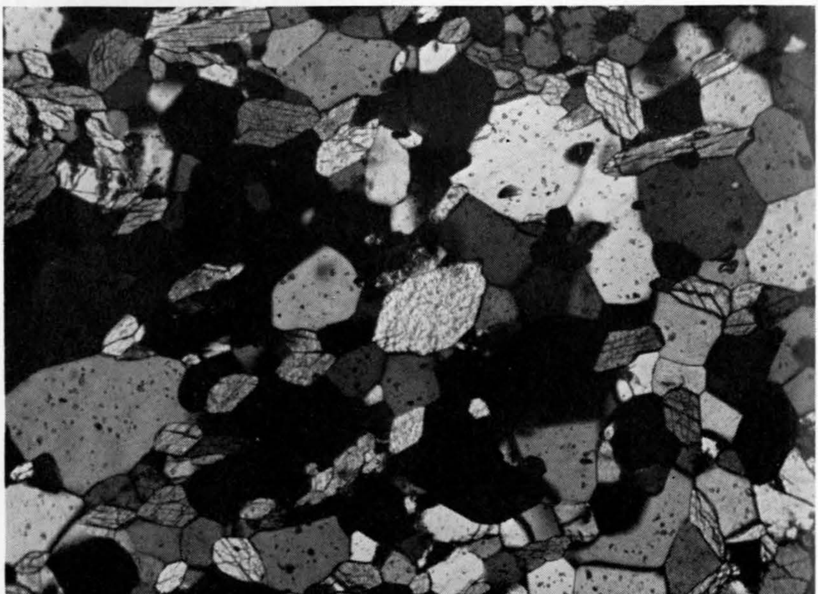

Figure 10.—Amphibolitic quartzite. Crossed nicols 40X. Rock from a road cut 1.9 miles N 8 W of Alford School.

Table IV contains Rosiwal analyses for four specimens. Specimens A and B are typical. A photo-micrograph of a typical specimen is shown in Figure 10.

Origin. Evidence favoring a sedimentary origin for the quartzite is as follows: Compositional banding resembling bedding, similarity of chemical composition with that of known graywackes Pettijohn (1949, p. 250) and occurrence interlayered with recognized meta-sediments.

Biotite-plagioclase gneiss

Field description. The biotite-plagioclase gneiss is widespread but weathers readily. Weathered material identified with the biotite-plagioclase gneiss includes; a residuum of red clay containing quartz and a scattering of millimeter-size, golden mica flakes, and saprolite exposures containing gneissic banding.

Layers of biotite schist, amphibolitic quartzite, granite, rarely spessartite-quartz rocks, sillimanite-graphite schist, sillimanite-mica schist and feldspathic amphibolite gneiss occur as irregularly distributed bands, lenticles and pods ranging from one inch to several feet thick. Variations known only from saprolite are an even-grained, porous, flaggy rock which superficially resembles a sandstone and a rock which occurs in concentrically-banded pods composed mostly of clay.

The biotite-plagioclase gneiss in Reed Creek and Shoal Creek districts contains more granitic material, is slightly coarser grained, and has a little more muscovite than similar rocks from Ray district. In the southwestern part of Reed Creek District, the gneiss contains enough granitic material to be a migmatite.

The common biotite-plagioclase gneiss is a fine grained, dark-grey, even textured faintly banded rock. Biotite is recognizable in weathered flakes with a maximum size of about 2 mm. Quartz and feldspar are commonly so small that individual identification is difficult.

Microscopic description. The rock has a granoblastic gneissose texture, Figure 11. Quartz and feldspar grains range from 0.1 to 0.5 mm. Biotite is a little larger and has reddish-brown pleochroism. Most of the plagioclase is untwinned and its composition ranges from An_{55} to An_{15}. Minor minerals are titanite, clinozoisite, apatite, epidote, garnet, chlorite, sulfides, oxides of iron, zircon and muscovite.

Rosiwal analyses of eight specimens are given in Tables V and VI.

Origin. The biotite-plagioclase gneiss may have been derived from a sedimentary rock, perhaps a graywacke. Evidence supporting sedimentary origin is variation in the mineral composition of different layers. Furcron and Teague (1945, p. 15) in their work in Hart County consider the gneisses as derived from arkose or graywacke beds.

This rock unit resembles parts of the Carolina gneiss as described by LaForge (1913). It is also similar to parts of Crickmay's (1952, p. 8) gneiss facies of the Carolina series in Georgia.

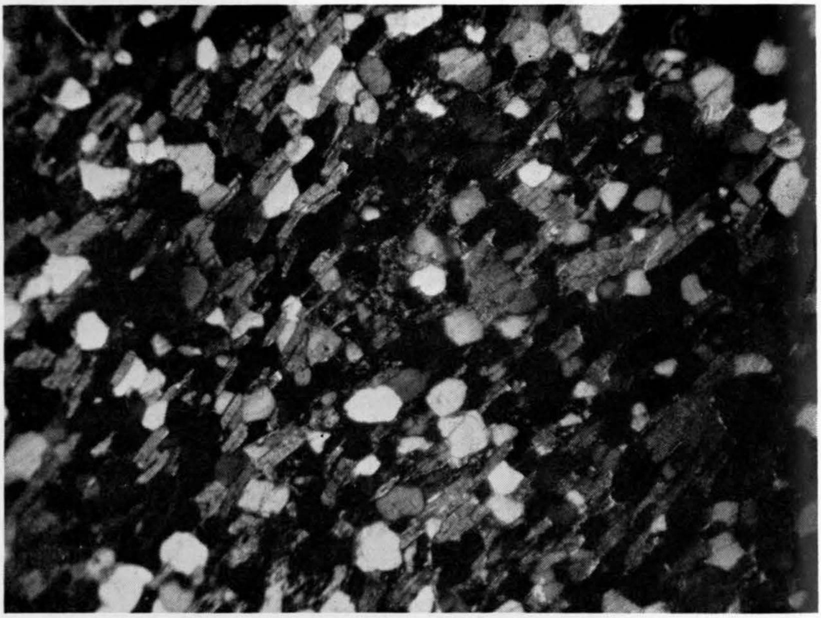

Figure 11.—Oriented biotite grains in biotite-plagioclase gneiss. Crossed nicols. 35X. Rock from old road cut 1.75 miles N88W of Redwine Church.

Table V—Modal Analyses of Biotite-plagioclase Gneisses from Ray District

	A	B	C	D
Biotite	4	27	36	29
Plagioclase	27	29	38	23
Quartz	66	43	25	49
Garnet	2	----	Tr	----
Epidote and Clinozoisite	----	Tr	Tr	Tr
Muscovite	----	Tr	1	----
Zircon	----	----	Tr	Tr
Titanite	----	Tr	----	Tr
Opaque	Tr	2	Tr	Tr

A. Biotite is red-brown. Plagioclase is An_{55}. The opaque material is principally sulfides. Location: 0.7 miles south of the Bowersville city limit in the West fork of South Beaverdam Creek.

B. The specimen contains strained quartz and is partially weathered. The placioclase is sericitized, sausuritized and kaolinized. The opaque matter consists of oxides of iron and titanium. Some of the biotite is altered to chlorite. Location: 1.7 miles due West of Redwine Church in a gullied road cut at a road intersection on the east side of South Beaverdam Creek.

C. The specimen is fairly well preserved. Biotite is red-brown. The plagioclase is An_{30}. Opaque matter is principally sulfides. Location: 2.1 miles due West of Redwine Church in a small branch which runs into South Beaverdam Creek.

D. This specimen is an inclusion in the granitic rock. It is badly weathered. Biotite is red-brown. Plagioclase is indeterminate. Opaque materials are hydrous oxides of iron and titanium. Location: 1.4 miles southwest of Goldmine near the east bank of Morea Creek.

Table VI—Modal Analyses of Biotite plagioclase Gneisses from the Reed Creek District and Smith District.

	A	B	C (a)	C (b)	D
Biotite	16	17	21	5	19
Plagioclase	30	38	52	22	34
Quartz	52	43	20	69	43
Garnet		Tr	1	Tr	Tr
Epidote and Clinozoisite	Tr		Tr	1	Tr
Muscovite	1	2	3	1	2
Zircon		Tr	Tr	Tr	
Titanite		Tr	Tr	Tr	
Opaque	1	Tr	3	1	1
Potash feldspar				Tr	1

A. The specimen was associated with some biotite schist and a little pegmatitic material. Biotite is green black. Plagioclase is An_{25}. Opaque matter is mostly magnetite. Location: a road cut 0.6 miles northwest of Reed Creek cross roads.

B. From the Tugaloo River 1.2 miles northwest of Hatton's Ford. The rock is a migmatite containing more biotite gneiss than schist. Biotite is red brown. Plagioclase is An_{15}. Opaque matter is pyrite and hydrous oxides of iron. Location: Tugaloo River 1.2 miles northwest of Hatton's Ford.

C. Red brown biotite is altered to chlorite. The plagioclase is An_{15} and is partially sericitized. Opaque matter is pyrite. (a) and (b) represent quartz poor and quartz rich bands in the same section. Location: 2 miles north of Reed Creek cross roads in the bed of Reed Creek.

D. Opaque matter is magnetite. Biotite is red brown. Plagioclase is An_{25}. Location: a mixed rock zone 2 miles northeast of Montevideo.

Spessartite-Quartz Rocks

Field description. These rocks are confined to a few stringers and float scattered through the biotite-plagioclase gneiss of the Shoal Creek District. The maximum observed thickness of the stringers is about two feet. Two kinds have been recognized; one is quartz-rich and highly resistant to weathering, the other is garnet-rich and somewhat less resistant.

Weathered specimens range from sooty black (garnet-rich variety) to brown, (quartz-rich variety). The color of a fresh specimen is unknown. The texture is sugary and foliation is evident.

Microscopic description. The garnet-rich variety has a granoblastic texture. Garnet ranges from .25 to .5 mm. in size and contains inclusions of quartz and graphite. Quartz forms a mosaic pattern. The quartz-rich variety has similar mineral relationships. A fibrous mineral resembling sillimanite is so decomposed and iron-stained that determination is uncertain.

Origin. Fermor (1909) described a remarkably similar spessartite-quartz rock from India which he called gondite. The principle difference is that the gondite has no graphite. Fermor was able to correlate the gondite with a relatively less metamorphosed sedimentary sequence where manganiferous layers are interstratified with layers of silt, clay and sand. The similarity between the two rocks supports a sedimentary origin.

Feldspathic amphibolite gneiss

Field description. This unit is a complex dominated by feldspathic amphibolite gneiss but containing biotite-plagioclase gneiss, granitic layers and some biotite bearing amphibolite gneiss. A few areas outside of that shown on Plate I have small quantities of the amphibolite. The saprolite, characterized by blocky, porous, ochre colored clay, is the common surface criterion for mapping. Layers of biotite-plagioclase gneiss and granitic saprolite are exposed only in deep gullies. Outcrops of amphibolite gneiss range in width from a few feet to nearly 100 feet.

The most common feldspathic amphibolite gneiss is an inequigranular rock speckled with white feldspar. The grain size ranges from 1 to 3 mm. Hornblende crystals lie with their prismatic cleavages parallel or sub parallel to the foliation. Less commonly the minerals may be differentiated into alternating dark and light bands of hornblende and feldspar. Bands of yellowish-green epidote also occur.

Microscopic description. The common rock is inequigranular and has nematoblastic texture, Figure 12. Strongly pleochroic hornblende grains are elongated parallel to the foliation. Plagioclase grains, some of which are serticitized and saussuritized, range in composition from sodic andesine to sodic labradorite. Intergrowths and overgrowths of plagioclase on plagioclase suggest that more than one generation exists. Minerals of minor importance are titanite, quartz, clinozoisite, epidote, and biotite. Traces of calcite, pyrite, magnetite, chlorite and leucoxene are occasionally present.

Rosiwal analyses of two typical feldspathic amphibolites and one biotite amphibolite are given in Table XI.

Origin. Amphibolites similar to specimens A and B have been formed by metamorphism of gabbros Eskola, (1914), basic lavas, Osborn, (1936, p. 205) and by replacement of limestone, Buddington, (1939, pp. 168-169). No evidence favoring any particular origin has been found.

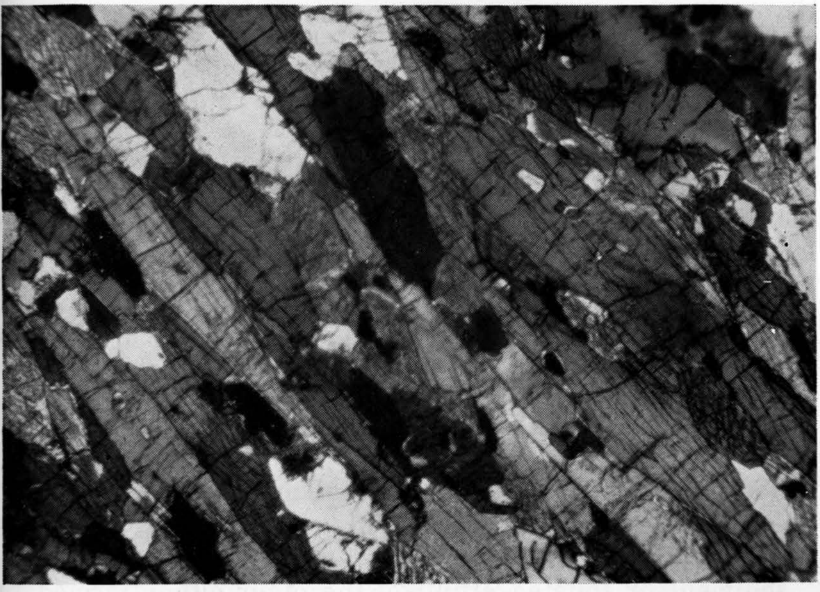

Figure 12.—Nematoblastic texture in a feldspathic amphibolite gneiss. Crossed nicols, 35X. Rock from road cut 2 miles N26E of Cross Roads Church.

Table VII—Modal Analysis of Feldspathic Amphibolite Gneisses.

	A	B	C
Hornblende	65	65	12
Plagioclase	17	26	40
Epidote	13	4	7
Quartz	3	3	31
Titanite	1	2	Tr
Biotite	Tr	Tr	10
Muscovite		Tr	Tr
Pyrite			Tr

A. Feldspathic amphibolite gneiss. Plagioclase composition varies from An_{70} to An_{50}. Location: 1.3 miles southeast of Viola Church.

B. Feldspathic amphibolite gneiss. Plagioclase An_{70}. Location: road cut 0.2 miles east of the main branch of Little Shoal Creek on Georgia highway 77.

C. Biotite amphibolite gneiss. Plagioclase $Ab_{65}An_{35}$. Location: Pooles creek 0.8 miles north of Georgia highway 77.

Mixed Rock Zone

This is a complex of biotite-plagioclase gneiss, augen gneisses, muscovite and biotite schists which sometimes carry garnet and/or sillimanite, feldspathic amphibolite, feldspathic-biotite schists, augen biotite schists, quartzose-mica schists, muscovite-biotite-plagioclase gneisses and amphibolitic quartzites all injected with granitic material in layers ranging in thickness from fractions of an inch up to tens of feet.

The field criteria utilized in determining whether a rock outcrop should be mapped in the mixed rock zone are: the outcrop must be at least one-half granite and both schistose and gneissic rocks must be present.

Biotite-plagioclase gneiss in contact with the biotite granodiorite gneiss in the Shoal Creek and Reed Creek districts lacks sufficient schistose material to satisfy the above definition, but some of it is certainly migmatite.

Microscopically the schists and gneisses of the mixed rock zone differ from similar rocks elsewhere. Muscovite is generally more abundant and the rocks are somewhat coarser. Augen textures are confined to this zone.

Sederholm (1907, p. 110) defined migmatite as follows:

> For the gneisses here in question, characteristic of which are two elements of different genetic value, one, a schistose sediment or foliated eruptive, the other either formed by the resolution of material like the first or by injection from without the author proposes the name migmatite . . . the

> position of this rock group being intermediate between eruptive rocks proper and crystalline schists of sedimentary or eruptive origin.

This definition applies to the rocks described above. However, the term as used herein includes only intimately injected rocks.

GRANITIC ROCKS

General Statement.

Definition. The term granitic rocks includes all light colored, granular rocks whose compositions range from granite to granodiorite.

Classification. The field classification of the granitic rocks is based on: the kind of mica present, the presence or absence of strong gneissic banding and the occasional presence of garnet and/or tourmaline. This criteria gives rise to two main groups; biotite and muscovite granites and biotite granite gneiss.

Johannsen's (1931) classification places most specimens of biotite and muscovite granite with either adamellites or granodiorites and rarely with the granites. Most samples of the biotite granite gneisses belong with the adamellites and granodiorites and rarely with the granites and the tonalites. A slight majority of the rocks examined were granodiorites. Hence, the rocks are shown on the map as granodiorites and granodiorite gneisses.

The true average rock is probably richer in plagioclase than the average of the rocks examined; because potash feldspars are more resistant to weathering.

The staining method of Gabriel and Cox (1929) as modified by Chayes (1952) was used for distinguishing potash and plagioclase feldspars during Rosiwal analysis.

Granodiorites

Field description. The granodiorite occupies a deeply weathered area, with low relief, in the central and southwestern part of the county. Peripheral and outlying bodies can be identified as sills, phacoliths and dikes. The central masses are probably formed by coalescence of the smaller peripheral bodies.

North of the Hartwell Railroad pegmatitic, porphyroblastic and graphic varieties occur in addition to the equigranular muscovite granodiorite. South of the railroad only occasional pegmatites occur. Southwestward, especially in Ray District, biotite predominates over muscovite producing the biotite granodiorite. Muscovite and biotite granodiorites appear gradational and are only partially separable on the geologic map.

The common variety of granodiorite is a white to grayish-white 0.5 - 2 mm. grained rock. In places foliation is weakly developed. The megascopic minerals are quartz, feldspar, biotite, muscovite and locally garnet and tourmaline. Porphyroblastic varieties have a groundmass similar to the common variety, but contain irregular masses of feldspar as large as 10 cm. Pegmatitic varieties have a grain size larger than one centimeter.

Microscopic description. The rocks are inequigranular with most of the grains between one and two millimeters. Amoeboid shaped quartz grains are often fractured and sometimes exhibit undulatory extinction. Quartz contains streaks of opaque dust. Muscovite is embayed and sometimes bent, but in general is the most euhedral mineral found. Biotite occurs occasionally as ragged and bent grains and is not as well developed as muscovite. Plagioclase ranges from An_{15} to An_8. Albite and pericline twinning is seen in many grains, others have no twinning. Potash feldspar, usually microcline, occurs

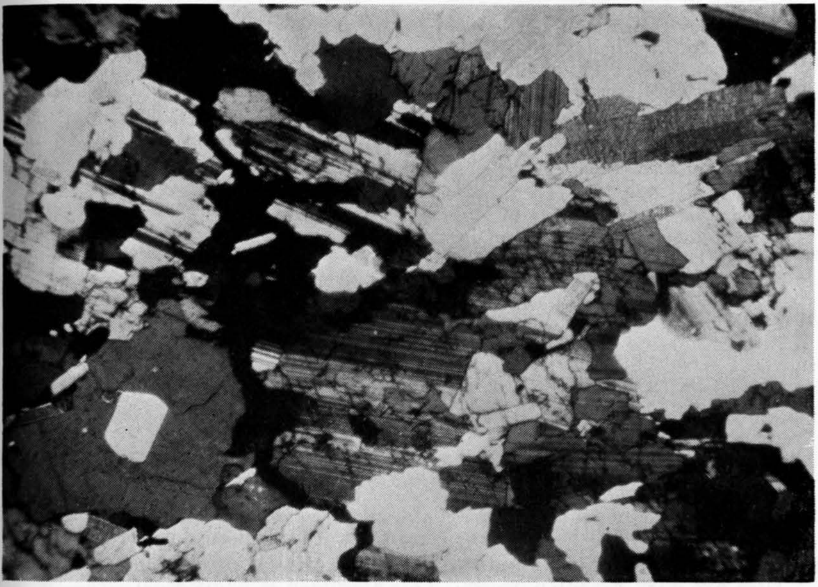

Figure 13.—Fractured plagioclase in muscovite granodiorite. Crossed nicols. 35X Rock from 2 miles S72W of Eagle Grove School.

both twinned and untwinned. The large porphyroblasts are dominantly microcline but usually include some plagioclase. Garnet occurs both in euhedral and anhedral grains. Tourmaline is euhedral and usually fractured. Intergrowths of quartz and mica, quartz and felds are rarely seen.

Rosiwal analyses of the muscovite granodiorite are given in Table VIII and the biotite granodiorite and graphic granite in Table IX. Figure 13 is a photomicrograph of the typical granodiorites.

Table VIII—Modal Analyses of Muscovite Granodiorites

	A	B	C	D	E	F	G
Muscovite	18	1	7	7	15	3	Tr
Biotite	4			1			2
Quartz	42	23	28	27	32	31	34
Potash Feldspar	15	25	12	11	21	27	28
Plagioclase	20	52	52	50	32	31	36
Garnet			Tr	5		Tr	Tr
Tourmaline						3	

A. Specimen taken from the banks of Coldwater Creek 1.1 miles northeast of Eagle Grove School. Biotite is reddish brown. Plagioclases are: twinned An_{12}, untwinned An_8. Location: 1.1 miles northeast of Eagle Grove School in Coldwater Creek.

B. Biotite is greenish black. Plagioclase is An_{11}. Location: 1.3 miles northwest of the Vanna city limits on Georgia highway 17.

C. Plagioclase is An_{15}. Location: 1.1 miles southeast of Airline on the north branch of Lightwood Log Creek.

D. Specimen taken from the west side of the east branch of Morea Creek 0.4 miles southeast of Macedonia Church. Biotite is greenish black. Plagioclase is An_{15}. Location: On Morea Creek 0.4 mile southeast of Macedonia Church.

E. Specimen taken from a road side 0.6 miles southeast of Goldmine. Plagioclase is An_{11}. Location: a road cut 0.6 miles southeast of Goldmine.

F. Float. Plagioclase is An_{10}. Location: 1.7 miles east of Vanna on the pipe line.

G. Biotite is reddish-yellowish brown. Plagioclase is An_{15}. Porphyroblastic type. Location: 0.4 miles northwest of Flat Shoals Church in a ford across Flat Shoals Creek.

Table IX—Modal Analysis of Biotite Granodiorite

	A	B	C
Biotite	5	7	Tr
Muscovite	4	5	Tr
Quartz	32	36	18
Plagioclase	35	32	2
Potash Feldspar	24	20	80
Epidote	Tr	----	----

A. Specimen taken from the east bank of Morea Creek 1.4 miles southwest of Goldmine. The biotites are red brown. The plagioclase is Ab_{89}.

B. Specimen taken from a gully 2.3 miles southwest of Goldmine. The biotites are dark greenish brown. This specimen is badly weathered.

C. Graphic granite taken near where the road crosses the north fork of Flat Shoals Creek, 1.2 miles southwest of Mt. Olivet Church.

Biotite Granodiorite Gneiss

Field description. The gneiss underlies two areas; a southeastern area characterized by low relief and sparse outcrops, and a northwestern area of similar character except for the northern one-third of Shoal Creek District where outcrops are common and relief is high.

Typical biotite granodiorite gneiss is a strongly banded, 2 to 3 mm. grained, greyish-white rock. Bands result from the alternation of biotite-rich and biotite-poor layers. Locally knots of white or rarely pink feldspar, averaging about 1 cm. in size, are scattered in the rock. Scattered partings of biotite schist, 5 by 30 cm., sparse amphibolite layers and biotite pegmatites occur in the gneiss. Feldspar, quartz and biotite are the principal megascopic minerals, but magnetite and epidote are locally abundant. A biotite poor zone in the granodiorite containing lumps and subhedral magnetite, grain size ranging from 2 to over 15 mm., is shown on Plate I. A Rosiwal analysis of this rock is given in Table Xb, column F.

Microscopic description. The rock is inequigranular, with grain size ranging from .05 to 7 mm. with an average of about 2 mm. Quartz is irregular in outline. Some grains include aligned streaks of opaque dust and others show undulatory extinction. Subhedral muscovite shows ragged outlines and occasionally is partially replaced, Figure 14. Biotite, pleochroic in olive-brown colors, shows a ragged outline and locally is altering to chlorite. The existance of two or more generations of plagioclase is shown by zoned crystals which usually have a calcic core and a sodic rim, Figure 16. The cores contain no inclusions but are occasionally sericitized. Saussuritized grains also occur, Figure 15. Plagioclase ranges from An_{30} to An_{12}. Microcline is anhedral and may or may not show twinning. Perthite is rare. Complex interrelations between plagioclase and microcline are shown in Figure 16. From textural studies the usual sequence of feldspar development is early plagioclase replaced by microcline which may be replaced by later plagioclase. Accessory minerals are zircon, apatite, titanite, magnetite and epidote.

Chemical and Rosiwal analyses are given in Tables Xa and Xb.

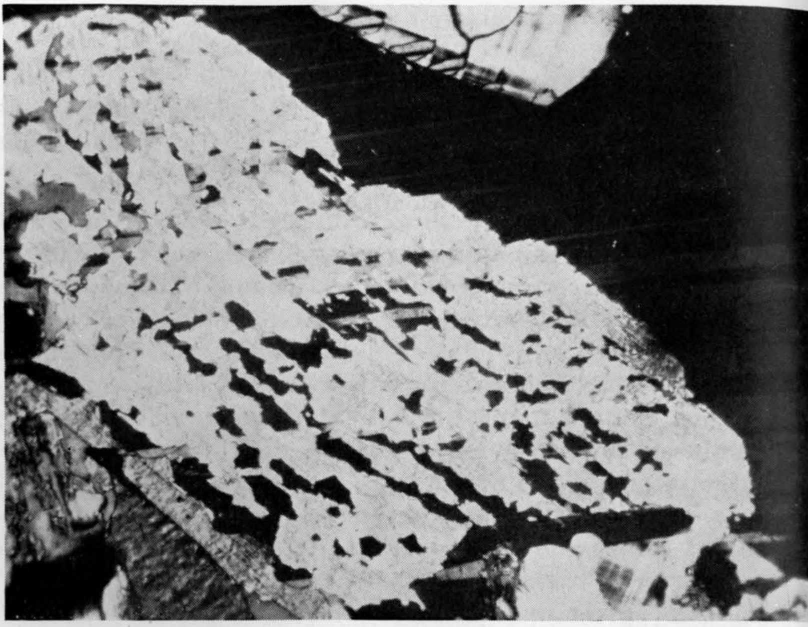

Figure 14—Plagioclase replacing muscovite. Crossed nicols. 40X, Rock from the Quarry 0.7 miles S40E of Shoal Creek Church.

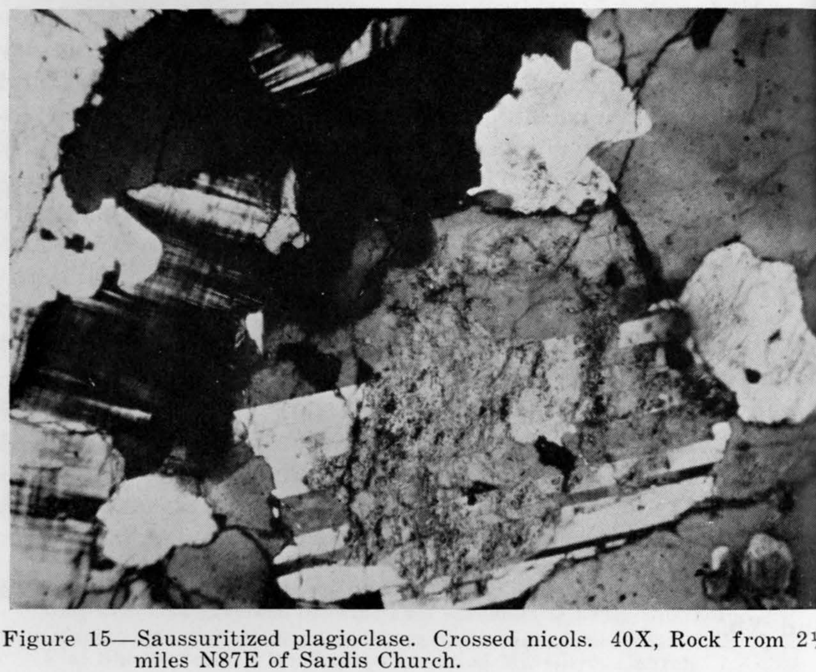

Figure 15—Saussuritized plagioclase. Crossed nicols. 40X, Rock from 2½ miles N87E of Sardis Church.

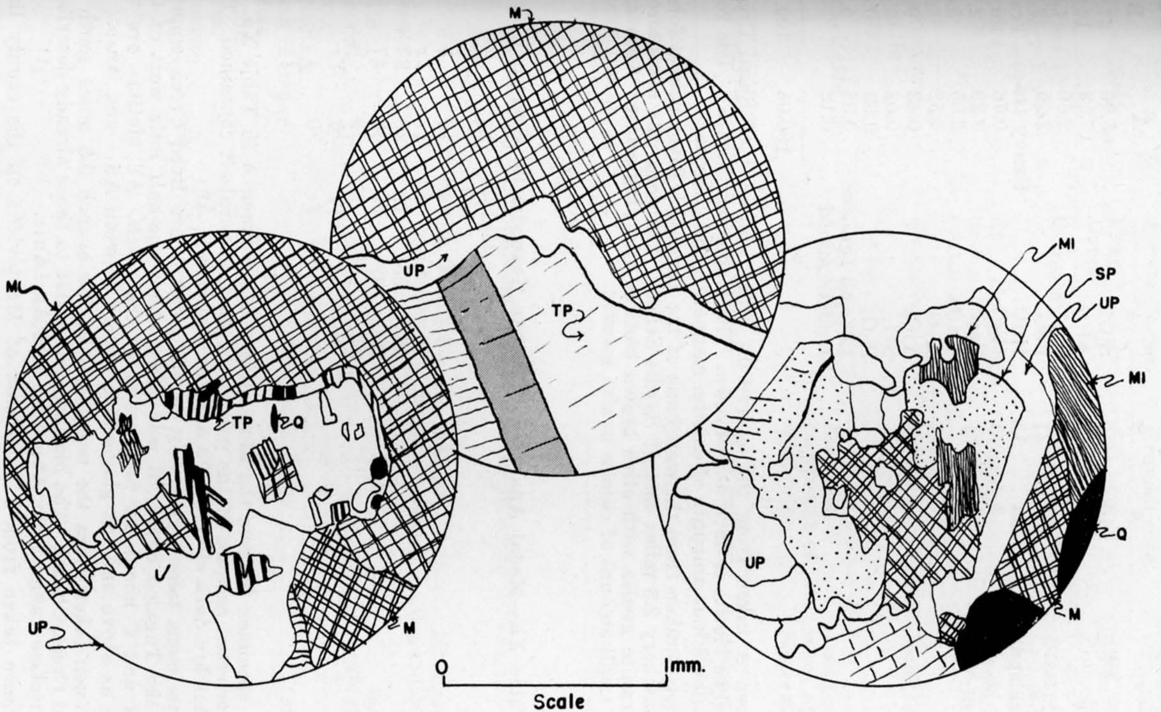

Figure 16—Feldspar association in biotite granodiorite gneiss, m-microcline, sp-sericitized plagioclase, up-untwinned plagioclase, tp-twinned plagioclase, mi-mica, q-quartz. Rock from the quarry 0.6 miles S40E of Shoal Creek Church.

Table Xa—Chemical and Modal analyses of Biotite Granodiorite Gneisses

Rosiwal Analysis

	A	B
Biotite	10	9
Muscovite	5	2
Quartz	13	34
Plagioclase	34	41
Potash feldspar	34	15
Epidote	3	1
Titanite	1	

Chemical Analysis by L. H. Turner

	A	B
SiO_2	65.96	67.15
Al_2O_3	17.13	16.90
Fe_2O_3	2.65	1.07
FeO	2.05	2.15
MnO	Heavy trace	Trace
MgO	0.76	0.70
CaO	0.29	2.70
Na_2O	5.00	5.05
K_2O	4.52	3.28
TiO_2	0.43	0.33
SO_3	0.62	0.47
P_2O_5	0.09	0.05
Loss on Ignition	0.35	0.30
Undetermined	0.18	
	100.03	100.15

Specimen A taken from the quarry 0.7 miles southeast of Shoal Creek Church. The biotite is dark olive-brown. The plagioclase is An_{12}. The rock also contains minor amounts of calcite, magnetite and chlorite.

Specimen B taken from the west bank of the Savannah River near a former fish hatchery 2.3 miles east of Sardis School. The rock was a contorted biotite granite gneiss with olive brown biotites and plagioclases An_{20} and An_{12}. A small amount of calcite is also present.

Table Xb—Modal Analyses of Biotite Granodiorite Gneisses

	A	B	C	D	E	F
Biotite	5	4	9	12	0	1
Muscovite	1	5	1	Tr	Tr	3
Quartz	35	25	19	23	37	35
Plagioclase	22	49	56	56	47	39
Potash feldspar	37	16	9	9	6	22
Epidote	1	1	Tr	0	Tr	Tr
Titanite	----	----	Tr	0	..	----
Magnetite	----	----	----	----	Tr	----

A. This specimen is from the same quarry as specimen A in Table Xa. It was selected because of the paucity of dark minerals it contained. The biotites are dark olive brown and the plagioclase An_{15}.

B.-C. Specimens taken from west of the point where Reed Creek empties into the Tugaloo River. B was taken about one-half mile west of the creek and C about 0.2 miles west of the creek. All biotites are the same as above and the plagioclases range between An_{15} and An_{10}.

D. Specimen taken from the north side of the branch 0.3 miles south of Shoal Creek Church. The biotites are similar to those already described. Plagioclase range from $Ab_{75}An_{25}$ and $Ab_{85}An_{15}$.

E. Specimen taken from 2 miles east of Montevideo on the county line. Plagioclase is $Ab_{75}An_{25}$.

F. Specimen taken from a roadcut 1.4 miles northwest of Cokesbury Church, near Cedar Creek. The biotite is olive brown. Plagioclase is $Ab_{75}An_{25}$.

Table XI—Comparison of the Various Granitic Rocks

	Biotite Granodiorite Gneiss	Biotite Granodiorite	Muscovite Granodiorite
Form of body	Phacoliths or Domes	Sill-like	Sills, Dikes Phacoliths
Relation to Country Rock	Concordant	Discordant in part	Discordant in part
Texture	Strongly gneissic sometimes contorted	Weakly gneiss	Weakly gneissic to massive
Injection and migmatic activity	Extensive	Limited	Limited
Contact effects	Very little	Local enlargement of minerals	Local enlargement of minerals
Metasomatism	None evident	None evident	Boron and Potash
Time relations as indicated by decreasing gneissic textures	First	Second	Third

Table XII—Comparison of Mineral Occurrences in Various Granitic Rocks.

Minerals	Biotite Granodiorite Gneiss	Biotite Granodiorite	Muscovite Granodiorite
Biotite	+	+	+
Muscovite	+	+	+
Quartz	+	+	+
Plagioclase	+	+	+
Potash feldspar	+	+	+
Epidote	+	+	----
Titanite	+	----	----
Garnet	----	+	+
Magnetite	+	----	----
Tourmaline	----	----	+

Table XIII—Optical Data on Various Minerals.

Mineral	Refractive indices*			Ext. Angle	Est. 2V	Opt. Sign	Pleochroism			Occurrence and Remarks
	Nx	Ny	Nz				X	Y	Z	
Microcline	1.519		1.526			—				Muscovite granodiorite. Indices measured on basal sections
Albite	1.530					+				Pegmatitic layer in Biotite-plagioclase gneiss. Index measured on 010 cleavage Untwinned plagioclase.
Daphnite		1.66± .01			10°	—	Pale yellow	Pale olive green	Greyish green	Altered staurolite-mica schist.
Penninite		1.59± .01			10°	—	Pale yellowish green	Green	Green	Alters from biotite usually in sheared rocks. Gelatinizes in HCl. Anomalous interference colors.
Biotite			1.646		10°	—	Colorless to pale yellow	Brownish gr. to black	Brownish green to black	Biotite granodiorite gneiss.

*All refractive indices ±.002 unless otherwise indicated.

Table XIII—Optical Data on Various Minerals. (cont.)

Mineral	Refractive indices*			Ext. Angle	Est. 2V	Opt. Sign	Pleochroism			Occurrence and Remarks
	Nx	Ny	Nz				X	Y	Z	
Biotite			1.629		10°	—	Colorless	Reddish brown	Reddish brown	Biotite-plagioclase gneiss
Biotite			1.634		10°	—	Colorless	Reddish brown	Reddish brown	Sillimanite-mica schist
Biotite			1.630		10°	—	Colorless	Yellow brown	Yellow brown	Biotite schist migmatite zone
Hornblende	1.645		1.666	Z ∧ C =23°	80°	—	Yellow	Yellowish green	Bluish green	Feldspathic amphibolite gneiss.
Hornblende	1.643		1.663	Z ∧ C =25°	80°	—	Colorless	Pale yellow	Pale green	Amphibolitic quartzite
Epidote		1.73± .01	1.75± .01	Z ∧ 001 =20°		—				Epidote layer in a feldspathic amphibolite gneiss. Thick fragments are grass green Indices measured on 001 cleavage fragments.
Clinozoisite		1.72± .01	1.72±	Z ∧ 001 =25°						Biotite plagioclase gneiss Indices measured on 001 cleavage fragments.

*All refractive indices ±.002 unless otherwise indicated.

Table XIII—Optical Data on Various Minerals. (cont.)

Mineral	Refractive indices*			Ext. Angle	Est. 2V	Opt. Sign	Pleochroism			Occurrence and Remarks
	Nx	Ny	Nz				X	Y	Z	
Muscovite		1.593	1.600		30°	—				Muscovite granodiorite
Muscovite		1.593	1.599		30°	—				Sillimanite-mica schist.
Staurolite		1.74± 0.1			85°	+	Colorless	Pale Yellow	Yellow	Staurolite mica schist. Weak rhombic dispersion r > v
Sillimanite	1.655		1.677		25°	+				Sillimanite-mica schist. Large crystals with good 010 cleavage
Sillimanite (fibrolite)	1.655		1.677							Sillimanite-mica schist. Specimen from a large fibrolite knot.

*All refractive indices ±.002 unless otherwise indicated.

Table XIII—Optical Data on Various Minerals. (cont.)

Mineral	Refractive indices* No	Refractive indices* Ne	Optic Sign	Pleochroism e	Pleochroism o	Occurrence and Remarks
Tourmaline	1.653	1.629	—	Pale yellow	Greenish brown	Muscovite schist
Tourmaline	1.663	1.632	—	Yellowish	Dark olive green	Muscovite granodiorite Pleochroism varies in different parts of the crystal.
Tourmaline	1.664	1.633	—	Buff	Brownish green	Sillimanite-tourmaline gneiss.

Mineral	Refractive Indices N	Color Thick Sec.	Color Thin Sec.	Occurrence	Remarks
Spessartite	1.78± .01	dirty yellow	colorless	Spessartite-quartz rock.	Contains inclusions of graphite
Rhodalite	1.75± .01	pinkish-violet	colorless	Sillimanite mica schist	
Almandite	1.81± .01	reddish brown	colorless	Sillimanite mica schist.	

*All refractive indices ±.002 unless otherwise indicated.

Origin of Granites

Williams (1895) recognized massive granitic rocks, in the middle Atlantic States, as being of igneous origin. His main criteria were: contact phenomena, cross cutting contacts, and chemical composition. When dealing with gneissic rocks he became more cautious, pointing to the existence of sedimentary rocks which might be metamorphosed into igneous looking rocks. He also was aware of the possibility that they might be metamorphosed granites. He knew that some workers believed that some gneisses were derived from re-fused sediments. In the case involving gneisses, Williams relied upon the chemical criteria as expounded by Rosenbusch as the prime factor in determining the origin of a rock.

Watson (1902) followed Williams entirely in determining the origin of the granites and gneisses of Georgia. He classified these rocks according to texture and mineralogy. In his opinion, the bandings in the gneisses are secondary structures induced by dynamo-metamorphism of an originally massive granite. On this basis he split the granites of Georgia into two groups; an older gneissic group and a younger massive group. This idea is still widely held and from the viewpoint of a field geologist is still useful.

Fenner (1914) in his work on the gneisses of the highlands of New Jersey observed contortions and corrosion of rocks included in a granitic matrix, and the preservation of delicate structures. His conclusions were that a viscous magma was quietly and gradually intruded. He further noted that many observed characteristics were suggestive of replacement by magmatic solution.

Larsen and Morris (1933) observed a schist containing pods and lenses of pegmatite and that the Fitchburg granite contains relic structures derived from the schist. Their conclusions were that hot ascending solutions invaded the schist, forming pods of pegmatite. Where the supply of solution was sufficient the whole mass of schist was taken into solution leaving only relics of schist. Thus, only locally was an ordinary intrusive magma present. This bears a remarkable similarity to the muscovite granodiorite bodies immediately southwest of Hartwell. It is here that the muscovite content of the rock gets as high as 20 percent.

C. A. Chapman (1952a, p. 1239) raises the possibility that the granitic gneiss domes of western New Hampshire may be better explained by the metamorphic-metasomatic theory. C. A. Chapman (1952b, p. 410) recognized three general theories in explaining the origin of certain granitic rocks. These are:

> **Magmatic**—the rocks differentiated from basaltic or some other magma, or they are of palingenic origin. (2) **Metamorphic**—the rocks were formed by recrystallization of a feldspathic sediment, a volcanic or a pretectonic igneous body. (3) **Replacement**—the rocks formed by recrystallization of the Littleton formation and the addition of limited amounts of material from a distant source.

Chapman concludes that the replacement hypothesis is to be preferred.

Kesler (1936) while working in South Carolina on granitic injection processes concluded that the most remote direct effects of the granites on the schists was hydrothermal recrystallization. Nearer the contacts, injection and replacement phenomena are found to have increasing effectiveness.

From this brief review of the ideas concerning granites in the eastern United States, one point emerges. Almost all workers from Fenner's time on have felt compelled to recognize the ability of granites to replace the country rock in varying degrees under high grade metamorphic conditions.

Bowen (1945) shows that excess alkali silicates may form from quenched rhyolite obsidians. This indicates that solutions necessary to bring about replacement are possibly obtainable. Furthermore, since an alkali silicate may be produced from a quenched rhyolite it seems possible that a similar solution might be obtained by raising the temperature of some pre-existing rock of proper composition. Eskola (1932b) stresses the possibility of orogenic stresses squeezing out the lowest melting fraction from partially solidified basic rocks and partially refused sedimentary rocks.

How does the solution get into the country rock to alter it? Experiments made by Morey (1922) indicate that during crystallization of a silicate mixture, the hydrostatic pressure of the volatile components becomes very high. This suggests the possibility that these high vapor pressures are responsible for driving the volatiles into the country rock. Such pressures would favor the escape of volatiles. However, the ability of this fluid to penetrate the wall rock is questioned by Fenner (1914, p. 696) and Ramberg (1952, p. 179) on the grounds that the pore spaces would be too small to permit the migration of these volatiles over any great distance by ordinary means in a highly compressed metamorphic rock. Harker (1939, p. 250) suggests that the mechanical movements which are associated with regional metamorphism facilitate the migration of pneumatolytic products into the country rock. Evidence favoring such conclusions in high grade metamorphic rocks is plentiful. Ramberg (1952) proposes a diffusion mechanism which will give a satisfactory account of the formation of some granitic masses. His views on the conditions favoring ion migration may be summarized as follows. It is known that temperature and pressure tend to increase with depth in the earth's crust. If a sedimentary rock at equilibrium with surface pressures and temperatures is downwarped into the depths of the earth, it is obvious that any pre-existing equilibrium will be destroyed. Under such conditions the rock will recrystallize in an effort to establish equilibrium with the new environment. If conditions in the recrystallized rock are such that the partial molar free energies of corresponding ionic species have the same value, no migration will take place. However, if the metamorphic conditions and the composition of the rock be such that the partial molar free energies of corresponding species cannot achieve equilibrium, then conditions favorable to the migration of matter exist. The mechanism for transporting this matter is seen as an intergranular network of absorbed atomic, ionic, and molecular material called "diffusion conductors." Thus, through these intergranular channels the fugitive material moves, driven by a chemical potential in an effort to reestablish equilibrium. In an earlier paper Ramberg (1951) gives what appears to be a concrete example of this mechanism. The rocks are downwarped into conditions of temperature and pressure compatible with the granulite facies. Some elements and molecular compounds are squeezed out of the rocks. Thermodynamics requires that H_2O, Si, K, Na and O be moved. These migrate upward and may cause granitization.

Daly (1933, pp. 293-294) postulated a mechanism whereby anatectic and hybrid rocks may be formed. To build this hypothesis, Daly assumes that during Archaen times, the crust of the earth was much thinner than it is today and therefore, the geothermal gradient was much steeper. It is assumed that this gradient made it easy for magmatic emanations to flux the supracrustal rocks and provide solutions for the formation of migmatites which are so conspicuous in Archaen terranes. Thus, the complexity of Archaen rocks is explained by regional anatexis, gas fluxing, assimilation and metasomatism.

Conclusions. In high grade metamorphic terranes where gradations are dominant, it seems unwarranted to assign either magmatic or metasomatic origin to a granite. The conclusion should be an estimate of the amount of magmatic and metasomatic activity. The following conclusions are drawn on this basis.

Muscovite and biotite granodiorites were possibly derived from a palingenic magma which because of compositional similarities, may have been derived from the biotite granodiorite gneiss. The magma was rich in volatiles as evidenced by boron and potash metasomatism. Possible hydrothermal activity is suggested by the alteration of staurolite to daphnite. Cross cutting contacts and contact metamorphism manifested by local enlargements of minerals favor a magmatic origin. Evidence suggesting replacement are the local excesses of muscovite and garnet in the contact zones and for some distance into the granodiorite mass. The presence of microcline porphyroblasts strongly suggests replacement, since they often include relics of the ground-mass. This fact was noted by Watson (1902) who observed that phenocrysts could not be of intratelluric origin since they were later than the groundmass. Hence, it is concluded that these rocks were dominantly magmatic and to a less extent of replacement origin.

The biotite granodiorite gneiss was possibly formed by ascending emanations which replaced the biotite-plagioclase gneiss. Evidence supporting this origin is as follows:

1. An amphibolitic quartzite which shows gradation into the gneiss and the general gradational character of the contacts.

2. The occurrence of the biotite granodiorite gneiss in a position where biotite-plagioclase gneiss would have been.

3. A single observed instance of a textural gradation from biotite granodiorite gneiss into granoblastic biotite-plagioclase gneiss.

Evidence favoring a magmatic origin is rather negative. However, it cannot be denied that the biotite granodiorite gneiss may be a metamorphosed igneous rock in which all characters indicative of such an origin have been destroyed by recrystallization.

METAMORPHISM

Metamorphic facies.

The facies classification of metamorphic rocks as set forth by Eskola (1920) and modified by Turner (1948) is utilized.

All of the metamorphic rocks, with the exception of occasional retrograde rocks, belong to the amphibolite facies. The principal sub-facies are: the staurolite-kyanite represented by the staurolite-mica schist, and the sillimanite-mica schists and gneisses. Definite subfacies cannot be assigned to either the biotite-plagioclase gneiss or the feldspathic amphibolite gneiss.

Kinds of metamorphism

Three kinds of metamorphism are distinguished on the basis of different physical conditions. They are: regional, contact and kinetic metamorphism.

The high temperatures and pressures during regional metamorphism is indicated by the formation of metamorphic minerals and high shearing forces by their deformation. Figure 5 shows folded plume-like masses of mica in staurolite-mica schist. Folded fibrolite occurs in sillimanite-mica schist. Small flowage folds in feldspathic amphibolite gneiss suggest elevated temperature and shearing forces. Much of the evidence of movement has been obliterated by subsequent recrystallization which resembles the post-tectonic recrystallization of Sander (Fairbairn 1949, p. 39).

Contact metamorphism is best developed at contacts between granodiorite and mica schist where crystals of sillimanite, muscovite and garnet are enlarged from millimeter to centimeter size, in zones tens of feet wide. Contacts involving biotite-plagioclase gneiss produce only a little recrystallization of biotite in zones about a millimeter wide. The apparent random orientation of most recrystallized grains and porphyroblastic muscovite cross cutting the foliation suggests that the physical conditions were dominantly thermal. Chlorite derived from staurolite suggests that hydrothermal solutions were also present.

Evidence of kinetic metamorphism is found in scattered localized zones most of which are contained in the shear zone shown on the tectonic sketch map, Plate II. Chemical reconstitution is confined to alteration of biotite to chlorite. Evidence of movement includes granulation, bending and micro-faulting of grains.

Metasomatism. The country rock around the contacts of the muscovite granodiorites shows evidence of potash and boron metasomatism.

Potash metasomatism is suggested by relics of sillimanite-graphite schist enclosed in muscovite schist.

Two sources of potash are possible: the hydrolysis of potash feldspar in the late magmatic phase to form muscovite, a process which yields excess potash and silica, (Billings, 1938, p. 299); or the separation of an alkali rich aqueous phase from a consolidating granitic magma, analogous to a process described by Bowen (1945, p. 88).

Boron metasomatism is suggested by the presence of tourmaline in contact zones. It seems probable that the boron originated in the granodiorite since it contains tourmaline as well as the country rock. However, Goldschmidt and Peters (Rankama and Sahama 1949, p. 493) suggest that boron originally contained in a sediment may be concentrated in the contact zone because of its high mobility.

Evidence of metasomatism by the biotite granodiorite gneiss is shown by local development in contact zones of feldspar augens and a slight increase in the muscovite content of biotite-plagioclase gneiss.

STRUCTURAL GEOLOGY

Megascopic Structures.

General Statement. Sander's symbols as outlined by Cloos (1937, p. 62) are used in addition to the usual names applied to planes. Thus, bedding is S_1, foliation S_2 and cleavage S_3.

Sander's coordinates are used. As defined by Cloos (1945, p. 5) : **b** parallel to the fold axes, **a** perpendicular to **b** in the movement plane and **c** perpendicular to the **ab** plane. Axes of cross folding because of their variable relation to **b** are not given a letter designation to avoid confusion. Figure 17 shows the schematic relationships of the various structures to the coordinates except cleavage S_3.

Foliation. Schistosity and foliation, as defined by Turner (1948, p. 558), include all parallel metamorphic fabrics which give a megascopic fissility to rocks. Schistosity is seen as parallel micaceous layering usually associated with subordinate amounts of equant grains. Gneissic texture or banding is

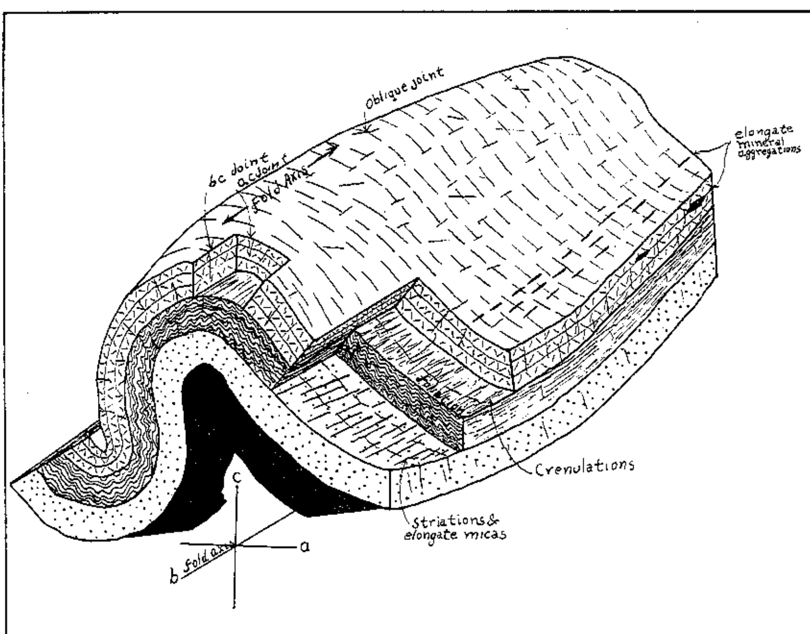

Figure 17.—The coordinates of deformation and their relation to the various structural elements.

seen as alternating light and dark colored layers predominantly composed of equant and subordinate amounts of micaceous grains. For structural purposes these planes are the same and are referred to as foliation (S_2).

The following discussion points out possibilities for the origin of foliation. The proof rests in areas where more extensive data are available.

Fairbairn (1935, p. 592) recognizes two types of foliation; one, parallel to bedding and the other parallel to the axial planes of folds. Two processes are recognized in the development of bedding plane foliation; a primary bedding foliation in which minerals are simply recrystallized in place, and a secondary bedding foliation in which shearing parallel to the bedding plane, accompanied by recrystallization, takes place. Dale (1895, pp. 155-158) recognized axial plane cleavage and bedding foliation. Billings (1937, p. 533) observed that foliation is often parallel to axial planes in low grade metamorphic rocks and in high grade rocks the foliation is apparently parallel to bedding. Engle (1949, p. 775) noted a prominent discordance between cleavage and bedding in the apices of isoclinal folds. These apical areas are rare, constituting one-tenth or less of the total outcrop. Folding the limbs of older isoclinal folds has taken place with axes only slightly askew from those of the earlier folding. In the younger folds cleavage wraps around the nose of the fold.

Relic isoclinal apices were not found probably due to deep weathering and the paucity of large out-crops where crests of folds might be observed. Since foliation (S_2) wraps around the noses of folds it is possible that the folds are the folded limbs of pre-existing isoclines.

Cleavage. Cleavage (S_3) has been identified in very few outcrops. It probably results from the same movements that produced the shear zone but proof is lacking. The cleavage (S_3) is defined in granites by elongate feldspar and quartz grains which transect the mica foliation (S_2).

Lineation. According to Cloos (1946, p. 1), lineation is a nongenetic, descriptive term applicable to a variety of structures which are capable of definition by a straight line.

The most common linear orientation in metamorphic rocks is parallel to **b**, Cloos (1937, p. 70). Broedel (1937, p. 70) observed a close structural relationship between lineation and fold axes in the gneiss domes near Baltimore. Billings (1941, p. 913), observed lineations which are generally parallel to fold axes in New Hampshire. C. A. Chapman (1952, p. 404) noted lineation normal to and parallel with the fold axis, and also noted that **a** lineation is the more frequently observed.

The following lineations have been observed:

a) Axes of large folds, 2-100 feet from limb to limb.
b) Crenulations and wrinkles, less than one inch from limb to limb.
c) Elongation of mineral grains, mainly mica.
d) Elongation of mineral aggregates.
e) Striations.

Three varieties of lineation, all approximately parallel, are distinguished on the Geologic Map, Plate I. They are mica lineations and striations, crenulations, and the axes of larger folds.

Mica lineations are parallel streaks of elongated mica plates found on foliation planes (S_2). They are always parallel to **b** and occur most abundantly in schists. The maximum observed ratio of length to width of the micas is 7:1. According to Cloos (1946, p. 30), the extension of grains parallel to **b** is limited by the arcuation of **b**. Elongation of grains by arcu-of **b** may be 1.5 to 2 times. Therefore, these lineations are probably the result of movement parallel to **b** in excess of that generated by arcuation and were probably formed by the same movement which caused shearing and cross folds. Striations parallel to **b** support this view.

Striations are grooves or ribs confined to surfaces on competent rocks such as quartz veins and amphibolitic quartzites. Cloos (1946, p. 8) suggests that such structures are indicative of movement.

Aggregates of minerals are often elongated parallel to **b**. Pegmatite pods similar to Figure 18 have their long axes parallel to the mica lineation. Spindle-shaped clots of biotite are sometimes seen in the biotite granodiorite gneiss. Similar clots are known from many parts of the world, (Balk 1948, p. 12).

The lineation diagrams, Plate IV, show the trend of lineations and may be compared with the joint diagrams, Plate

III. The diagrams were prepared by plotting data from twelve approximately equal areas in the county. The diagrams were similar in roughly east-west belts, and therefore the three diagrams in each belt were combined into a single diagram which is marked by a Roman numeral. A corresponding Roman numeral on the inset map shows the area covered by each diagram. Not all measured lineations were used. Instead, an effort was made to get even distribution and avoid any fallacy that might result from using too many lineations from one area.

Folds. All folds are outlined by foliation (S_2) which wraps around their noses. They range from microscopic size to great anticlinoria and synclinoria measuring several miles from limb to limb. Only folds up to 100 feet from limb to limb will be discussed here.

Crenulations are small folds usually less than two or three inches from limb to limb. Their forms range from tight chevron folds with amplitudes twice the distance between the limbs and with axial planes overturned almost parallel to the foliation, to gentle undulations with amplitudes only a small fraction of the distance between the limbs and with axial planes nearly normal to the foliation.

Large folds range from about two to one-hundred feet between the limbs. Their external appearance in cross section ranges from broad open folds, to recumbent isoclinal folds, Figure 19.

Folds in the biotite granodiorite gneiss appear as small tight irregular contortions measurable in inches and as small open folds two or three feet between limbs.

Folds showing flowage are confined to the feldspathic amphibolite gneiss. They are steeply overturned and show thinning on the limbs and thickening in the crests, Figure 20.

Cross folds. These folds are distinguished by their large angular departure from the major fold trend. Plate IV shows the axes of cross folds as low percentage patches at high but variable angles to the main lineations.

Figure 21 shows a sheared cross fold. The lower part of the sketch is horizontal and the upper part vertical. Arcuation of the fold axis is shown on the horizontal plane. Figures 21 and 22 show the relation between folds and cross folds in a sillimanite-garnet-mica gneiss. Figure 23 shows the **ac** plane of the major fold and Figure 22 the **ac** plane of the cross fold. Figure 24 shows a slight angular discordance between the foliation (S_2) and the cleavage (S_3) which outlines the cross fold.

Cross folds are believed to be the result of late shearing which is associated with kinetic metamorphism. This belief is supported by the parallelism of cross fold axes with the trend of the shear zone, and the association of some cross folds with shearing.

Joints. According to Cloos (1937, p. 47) rock joints are a more or less regular arrangement of fractures along which there is little or no displacement. They may occur singly or in related groups over a large or small area. Their character is closely related to the rocks in which they occur. Granites

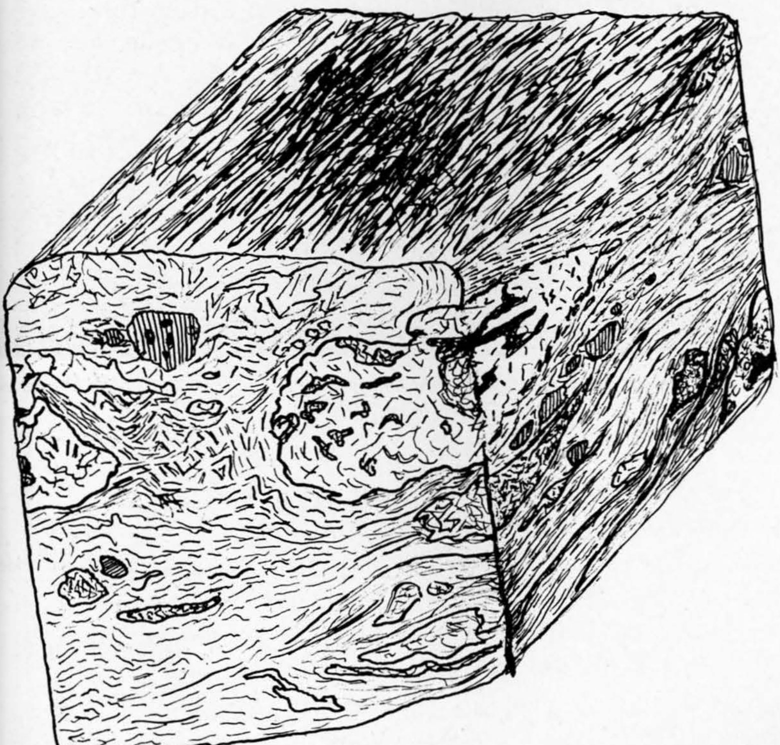

Figure 18.—Pegmatite pod elongated parallel to mica lineation. Twice actual size. Specimen from 0.75 miles S51W of Mount Olivet Church.

have smooth joint surfaces with area of many square feet. Joints cut feldspathic amphibolite gneiss into blocks similar to and about the size of brickbats. Joints in mica schists are poorly developed. Other rocks vary between amphibolite gneiss and mica schist in their joint development. Nearly all joints transect the foliation at high angles but a few occur at low angles. The ideal relationship of joints to the fold is shown in Figure 17.

Figure 19.—A recumbent fold in mica schist on the Southern RR about two miles north of Bowersville station.

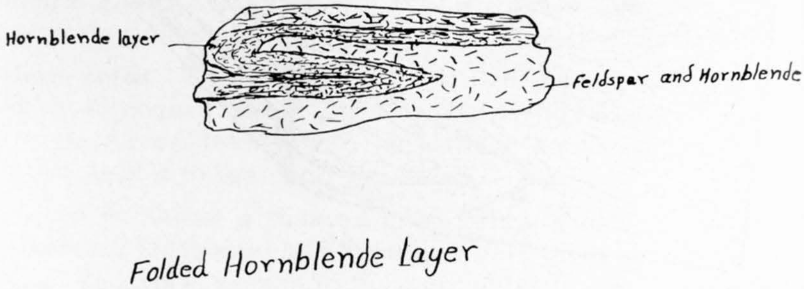

Figure 20.—A small flowage fold in feldspathic amphibolite gneiss. Actual size.

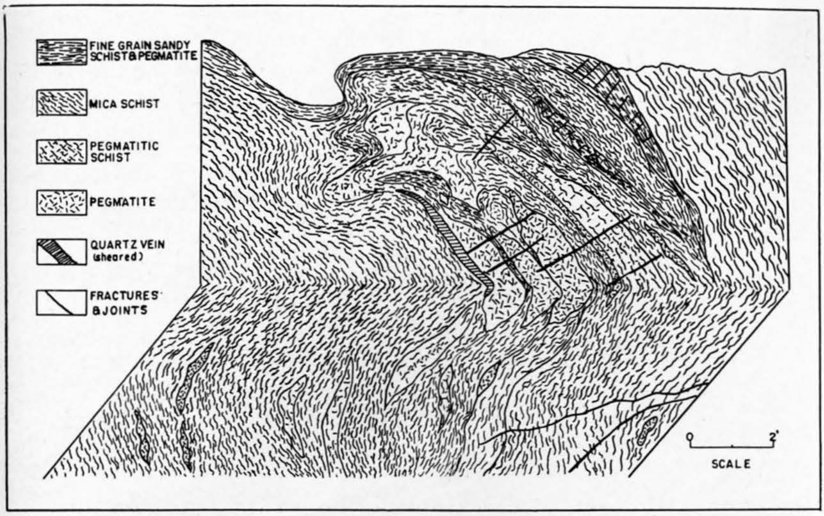

Figure 21.—A sheared cross fold in mica schist on Georgia highway 51 one-half mile west of Lightwood Log Creek.

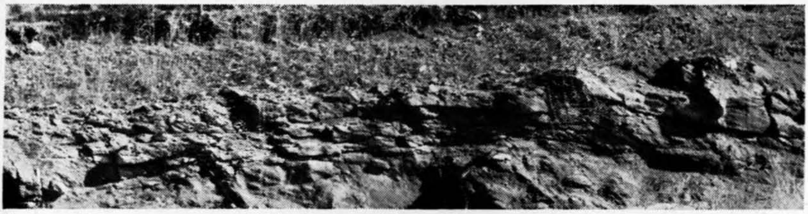

Figure 22.—A cross fold in a sillimanite-garnet-mica gneiss near Bio Church, facing east.

Figure 23.—The main fold on the same outcrop as above, but facing north.

Figure 24.—Details of joint surfaces. The cleavage (S_3) departs from the foliation (S_2), (parallel to the ruler) at a slight angle.

The **bc** joints are less abundant than **ac** but are equally widespread and consistent. Both are best developed in the biotite granodiorite gneiss and the feldspathic amphibolite gneiss. Oblique joints occur sporadically and have their best development in the same rocks as other joints.

Joints are not shown on the geologic map. Their regional distribution is shown on Plate III as a series of geographically located diagrams made by the same method as Plate IV. The diagram shows that **ac** joints are most common, followed by **bc** joints and only a scattering of other types. Comparison of the joint diagrams with the lineation diagrams, Plate V, shows that the **ac** joint poles migrate in sympathy with the lineation maxima. This suggests that jointing is related to folding.

Figure 25 shows the observed angles between the strikes of **ac** joints and lineations from a single outcrop. 60 percent of the 74 joints made angles between 80 and 90 degrees with the lineation and no joint made an angle of less than 50 degrees.

Jointing results from either tension or shearing. Some workers discount tension as a major cause jointing, (Kendall and Briggs, 1933, p. 170). Wager (1931) shows that joints in the Great Scar Limestone were probably the result of shearing and folding. However, neither of the mechanisms explains the joints systems described above.

It can be shown, by bending a bar of clay on which circles have been imprinted on both the upper and lower surface, that on the upper convex side of the bar, the circles are deformed into ellipses whose long axes are parallel to **a** while on the lower concave side the circles are deformed into ellipses whose long axes are parallel to **b**. This shows that tension is possible both normal and parallel to the fold axis. Fairbairn (1949, p. 156) notes that joints normal to the lineation may result from tension parallel to the fold axis. Hills (1953, p. 102) shows joints formed by tension normal to the fold axis.

Both joint sets are the result of tension possibly produced by either early folding or the late shearing.

Regional Structures.

General statement. The regional geology and cross sections are shown on the geologic map, Plate I. The tectonic sketch map, Plate II, shows the main structural features.

Cross sections. The idea that small structures are often the key to large structures was stated by Pumpelly, Wolff and Dale (1895, p. 158). Their statement is as follows:

> Such a correspondence exists between stratification and cleavage foliations of the great folds and those of the minute plications that a very small specimen, properly oriented, gives, in many cases, the key to the structure over a large portion of the side of a fold.

The cross sections were made by systematic projection of foliations (S_2) and lineations into a series of cross sections spaced at one-half mile intervals.

The principal facts gleaned from the cross sections are as follows. Larger folded structures in the area are synclinoria and anticlinoria in which the axial planes of the individual subordinate folds converge upward in the anticlinoria and downward in the synclinoria. This feature is referred to by Nevin (1949, p. 76) as abnormal. The axial traces of synclinoria and anticlinoria are shown on the tectonic sketch map. Plate II.

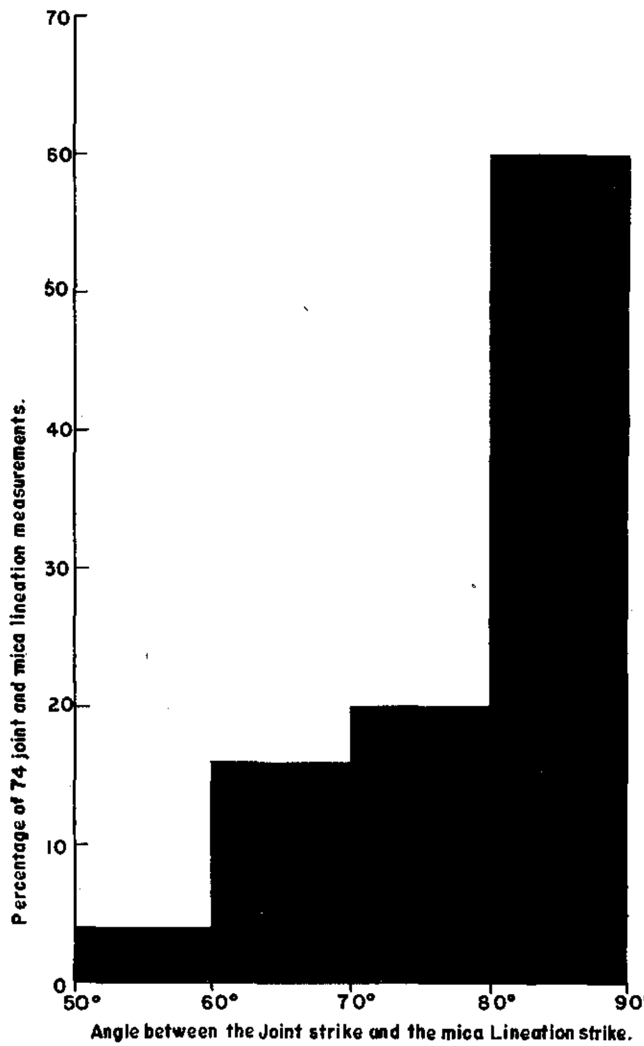

Figure 25.—The angular variation between ac joint strike and lineation strike.

Shear zone. The approximate boundaries of the shear zone are indicated on the tectonic sketch map, Plate II. The area simply indicates the loci of the majority of the observed structures which suggest shearing. These include cataclasites, minor faults, sheared folds and striations.

Faults. Two high angle faults are shown on the geologic map, Plate I. Evidence for these faults consists of an abrupt change in lithology across the diabase dike in one instance and a sheared pegmatite dike associated with a diabase dike in the other. The nature of the movement along these faults is unknown. Minor faults are sometimes seen, however, they are seldom if ever traceable over any distance. Figure 26 is a high angle fault of uncertain type. The sudden change in the attitude and the lithology of the involved rocks makes the fault obvious.

Petrofabric Analysis.

General statement. Two oriented specimens of sillimanite-garnet-mica gneisses were taken for analysis. The mineral composition of these rocks is given in Table III columns A and C. Selection was based on similarity in mineral composition and grain-size, in order to eliminate possible changes in the diagrams due to mineralogical variation. The relation of the specimen to large folds is known only for specimen A which came from the west limb of a slightly overturned isoclinal fold. A secondary consideration in selection was to obtain them from localities as far apart geographically as possible. A distance of 9.1 miles exists between specimens A. and B.

The object of the study was to determine the relation between field observations and petrofabric data.

Diagrams. There are four mica and two quartz diagrams in Plate V. The mica diagrams show the concentrations of the poles of the basal cleavages of biotite and muscovite. The quartz diagrams show the optic axes of quartz grains. The minimum number of grains measured was 200 and the maximum 432. In all diagrams the b-fabric axis which is the megascopic lineation is as nearly as possible normal to the plane of the diagram. No rotation of the diagrams was found necessary.

The field orientation of the plane of the diagram is indicated by an arrow which gives its strike. Dips are represented

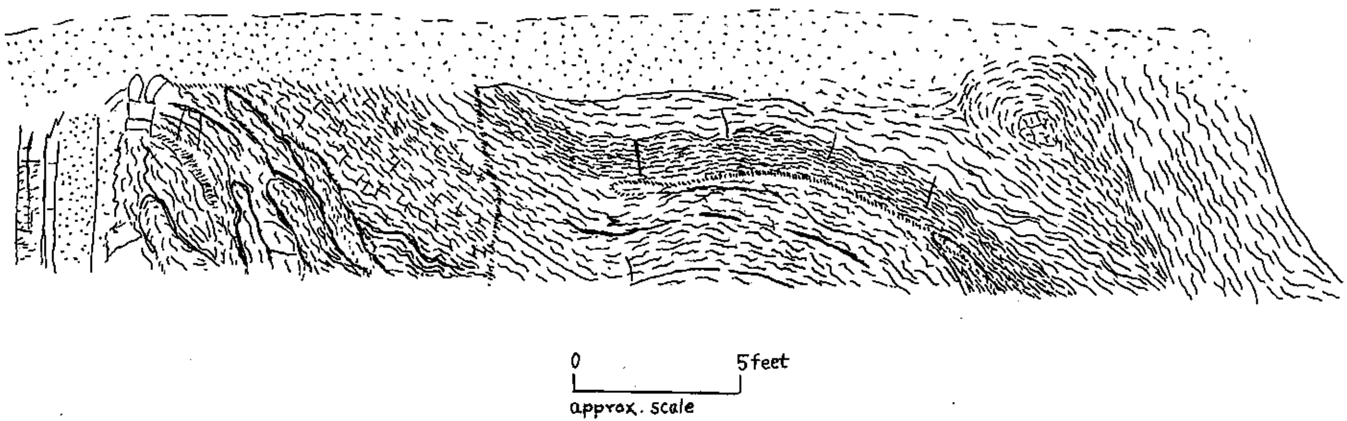

Figure 26.—A high angle fault between biotite-plagioclase gneiss and mica schist. Roadcut about one mile north of Hartwell.

by a short line normal to the arrow. Figures from 1° - 90° dip toward the observer. Those with numbers greater than 90° dip away from the observer. This is the system utilized by Cloos and Heitanen (1941, p. 37).

The counting of area percentages was done at every 1cm. intersection. Percentage area contours are shown by each diagram.

The diagrams were plotted in the lower hemisphere of an equal-area net from data obtained on the universal stage.

The location of each specimen is designated on the geologic map Plate I by the letters A and B.

Mica diagrams. The biotite diagrams 1A and 1B and the muscovite diagrams 2A and 2B have their main maxima normal to the **ab** plane which is the foliation (S_2). The extension of the six percent contour in the biotite diagrams may be related to the submaxima in the muscovite diagrams. Diagrams 1A and 2A show higher maxima and more complete girdles than diagram 1B and 2B. This suggests the intensity of deformation was slightly higher at locality A. The uniformity of the diagrams and their similarity implies fairly uniform deformation. The existence of a statistical S-plane normal to the muscovite submaxima may be a reflection of the late shearing movements which are sometimes visible as cleavages (S_3).

The maxima can be explained according to the ideas of Sander, (Fairbairn, p. 141, 1949) by rotation and translation parallel to (001). The proof of this would lie in a determination of whether the (100) glide line was parallel to fabric **a**. This has not been done.

Quartz diagrams. Correspondence between the two diagrams, 3A and 3B, is seen in the main maxima, the girdle and the peripheral maxima. There is considerable difference in the location of submaxima. The higher concentrations in the main and submaxima of 3A as compared with 3B supports the idea that deformation was more intense at A.

The maxima form an **ac** girdle which is explained by Sanders mechanism in which there is a rotation around **b** coupled with a movement in **a**. Another idea is that the maxima on the girdle correspond approximately with maxima caused by the intersection of rhombohedral cleavages in quartz as postulated in the fracture hypothesis of Griggs and Bell (1938). This orientation is one which Fairbairn (1939) predicted as being abundant and the work of Cloos and Heitanen (1946) substantiate it. The peripheral submaxima in both diagrams probably corresponds to maxima II of Fairbairn (1939, p. 1478). Maxima II is developed by needles bounded by either the positive or negative unit rhombohedron and a second order prism. If this interpretation is followed then it may be assumed that this maxima is associated with an S-surface other than the megascopic foliation. Projection and comparison of this S-plane with that previously suggested in the muscovite diagrams shows an approximate correspondence. This rather tenuous comparison when coupled with existing field data suggestive of shearing supports the idea that this second S surface is probably cleavage (S_3).

Conclusions.

1. Diagrams are in themselves only partially interpretable; handspecimen, outcrop and gross field relations must be considered.

2. The diagrams show the megascopic foliation (S_2) to be the dominant S-plane.

3. Lineation and the **ac** girdle relations plus field relations show both specimens to be B-tectonites where b = B.

4. The statistical S-plane is probably parallel to cleavage (S_3).

SUMMARY AND CONCLUSIONS

Summary.

Hart County is an upland area of low relief with local areas of marked dissection in the vicinity of major streams.

The effects of chemical weathering dominate the surficial part of the county.

With the exception of stream alluvium, the entire county is underlain by granitic and metamorphic rocks. The granitic rocks are texturally variable muscovite and biotite granodiorites and biotite granodiorite gneisses. The principal metamorphic rocks are staurolite-mica schist, sillimanite-garnet-mica schists and gneisses, biotite-plagioclase gneiss and feldspathic amphibolite gneiss. The mixed rock zones associated with the biotite granodiorite gneisses consist of various metamorphic rocks injected with granitic material giving rise locally to migmatites, injection gneisses, etc.

The regional structures are large anticlinoria and synclinoria which have been sheared in a Northeasterly trending zone.

All of the metamorphic rocks belong to the amphibolite facies. Where shearing has been effective local retrogression of mineral assemblages occurs.

Previous workers. A rough geologic sketch map and a brief discussion was published by Baker (1933, p. 60). The geology of the county is also shown in gross outline on the Geologic Map of Georgia (1939). Furcròn and Teague (1945) mapped the belt of crystalline sillimanite schists and gneisses in the south central part of the county.

Data concerning the mica bearing pegmatites has been published by Furcron and Teague (1943) and Jahns and Lancaster (1950).

Conclusions.

The original sediments were probably deposited in water. Following deposition, these rocks were down-warped into the crust of the earth where they were subjected to elevated temperatures, shearing stresses, and hydrostatic pressures. This change from surficial to deeply buried conditions resulted in metamorphic reactions and recrystallization. It was during this time that the synorogenic biotite granodiorite gneisses came into existence probably by metasomatic alteration of preexisting biotite-plagioclase gneisses. The differential movements associated with regional metamorphism are responsible for the deformed condition of the rocks. Following the climax of regional metamorphism the deforming forces either ceased or were severely attenuated. The temperatures remained rather high permitting recrystallization of the deformed minerals. This was followed by local shearing movements. These movements possibly uplifted the previously folded rocks making room for the intrusion of muscovite and biotite granodiorites, which are possibly paligenic derivatives of the biotite granodiorite gneiss. This intrusion caused recrystallization of minerals in contact zones, and probably provided some hydrothermal solutions which were active in producing metasomatic alterations and aiding in recrystallization. As the temperature of the rocks dropped, the shearing movement continued. This situation yielded many rocks whose mineral assemblages show transitions to lower metamorphic grade.

For purposes of discussion, various periods of deformation and metamorphism have been separated. However, there is no reason to believe that these processes were anything but continuous and gradational one into another.

Until the age relations are known, the time involved in the development of the rocks and structures of this area remains unknown.

ECONOMIC GEOLOGY

Pegmatites.

General Statement: Pegmatites range from little pods measurable in inches to masses tens of feet wide and hundreds of feet in length. They occur in every rock type and in all parts of the county. They are larger and more numerous near large masses of granite and especially in part of the shear zone between Hartwell and Bowersville. Most pegmatites are concordant. Cross cutting pegmatites are usually smaller, occur less frequently, and as far as is known, none of them are of economic significance. The shapes most commonly seen are pods and lenticles which are elongated parallel to the banding or foliation of the enclosing rock.

The common minerals in pegmatites are soda plagioclase, potash feldspar, muscovite, biotite and quartz. Tourmaline and garnet occur in small quantities. Muscovite from Hart County is water clear in sheets less than 1/32 of an inch thick. Sheets about 1/8" thick have a pale, brownish-smoky, color.

Sheet Mica Pegmatites: The distribution of sheet mica pegmatites is shown on Plate I. Three types are indicated: mines, where considerable quantities of sheet mica have been extracted; prospects, where small amounts of mica have been extracted or exploratory digging has been done; and places where mica sheets as large as one by one inch or larger occur either in place or as float. Two pegmatite zones are shown on Plate I. They are areas where the density of outcrop and/or float suggest a large number of pegmatites. The zones do not imply continuity of any given pegmatite but a group of disconnected pegmatites. The zone between Hartwell and Bowersville is most promising and should be carefully prospected. The zone in northwestern Reed Creek District is characterized by burr rock with much of the mica too small for sheet. The possibility of other zones exists.

Classification of Pegmatites: Pegmatites are classified on the relative proportions of major minerals as they occur on the dumps. The classification has value in that it is related to the quality of the mica. Use of the classification is possible only on a particular exposure since one class might grade into another.

The classes are: mica-quartz pegmatites characterized by dumps containing principally mica and quartz. They usually contain large quantities of mica but it is small size and much of it has A-structure, ruling, etc. These pegmatites would probably produce good scrap mica along with some sheet. The Bailey Mine is typical of this type.

Mica-quartz-feldspar pegmatites are characterized by more or less equal proportions of the principal minerals. Mica is not quite as abundant as the mica-quartz pegmatites but size and quality is superior. Mines in this type should produce mostly sheet mica with a minimum of scrap. The Garner Mine is typical of this type.

Feldspar pegmatites are composed largely of soda and potash feldspars with lesser amounts of quartz and mica. The mica has no value but some of these might produce commercial feldspar. The locality shown on Plate I is a feldspar pegmatite, exposed in a creek, 12 feet thick.

Books of mica as large as 1½ inches square occur in mica schists. The quality of the mica is good but there is very little of it. Most occurrences of this kind are found within a radius of about 4 miles west of Hartwell.

Commercial Properties of Sheet Mica: The desirable properties of sheet mica are: it must be flat, clear, cleave smoothly, be free of cracks and spots. Clay staining results from weathering and will disappear with increasing depth. A-structure, ruling, tangle sheet etc. do not disappear with depth. Very complete information concerning the properties of sheet mica may be found in Furcron and Teague (1943), Heinrich, Klepper and Jahns (1953) and especially Jahns and Lancaster (1950).

Sheet Mica Mines and Prospects.

General Statement: Each mine and prospect is given a number which is shown on Plate I. At the time of visitation none of the mines were in operation. Most of them are badly caved and in some cases have been filled. Pits designated as small are so badly caved as to make estimation of the original size difficult but a small hole is approximately 10 feet square.

Truitt D. Garner Mine (Location No. 1)

A mica-feldspar-quartz pegmatite located northeast of Macedonia Church. This mine was one of the biggest sheet mica operations. The existing pit is about 40 feet square, 18 or 20 feet deep, and is partially filled with water. According to local sources sheets of good quality muscovite up to about 5 by 7 inches were mined. Quartz, scraps of good quality mica and kaolinized feldspar occur on the dump. In the area around the mine there are several other pegmatites which should be explored.

Sam Bailey Mine (Location No. 2)

A quartz-mica pegmatite located south of Cross Roads Church. There are three small pits on the property which are partially filled. According to local sources the mica produced was very abundant but not the best quality. The dump shows large quantities of muscovite in sheets up to 2 by 5 inches. The other minerals are quartz and a little kaolinized feldspar. Some muscovite sheets are ruled, clay stained, have A-structure and are bent while others are clear and sheet well. This mine might make a good scrap mica operation with some sheet production.

T. J. Cunningham Prospect (Location No. 3)

A mica-quartz-feldspar pegmatite located south of the center of Hartwell. Two small pits on the property are partly caved. The mica is distributed around the edges of a partially exposed quartz body. The strike of the enclosing rocks is roughly east west with gently dips both north and south. This suggests a nearly horizontal pegmatite. Sheets of clear muscovite up to 3 by 5 inches occur in the saprolite. Larger pieces show A-structure, ruling and some are bent.

Luther Shiflet Mine (Location No. 4)

A mica-quartz-feldspar pegmatite located southeast of Oak Bower Church. The pit was originally about 15 feet square but has been partially filled. Clear muscovite may be found in books up to 4 by 4 inches with good cleavage. Books up to 6 by 8 inches are reported to have been produced. The muscovite has some ruling and A-structure.

J. B. Gaines Prospect (Location No. 5)

A mica-quartz-feldspar pegmatite located northeast of Nuberg. The pegmatite plunges steeply northeast and is divided by a granite horse. The pit is 9 by 12 feet and is 5 feet deep. The mica is clay stained, with ruling and A-structure on some sheets. Muscovite books up to about 3 by 6 inches occur around quartz veins in the pegmatite.

Mack Carter Mine (Location No. 6)

A mica-quartz-feldspar pegmatite located west northwest of Montevideo. The pit appears to have been 15 or 20 feet in diameter and is said to have been 25 to 30 feet deep. Good easily cleavable muscovite up to 3 by 3 inches occurs on the dump. Larger pieces are ruled and have A-structure. Clay staining and spotting occurs.

It is reported that mica has been mined at two other localities in this area.

J. B. Lewis Prospect (Location No. 7)

A mica-quartz-feldspar pegmatite located southwest of Alfords School. The pits have been completely filled. Float suggests the nature of the pegmatite. It is reported that mica sheets up to 5 by 5 inches were taken. The mica cleaves easily and only a minor amount of ruling occurs.

Chapman Mine (Location No. 8)

A mica-quartz-feldspar pegmatite located southwest of Cross Roads Church. This mine is said to have been worked prior to World War II. It was a large mine judging by the dump. There is a partially water filled shaft, probably well over 30 feet deep. The mica is spotted, cleaves easily, A-structure and ruling are rather rare. Two smaller prospect pits occur in the immediate vicinity of the mine.

Joe Findley Prospect (Location No. 9)

The prospect is located northeast of Vanna. The pit has been completely filled. Sheets of mica with A-structure and ruling up to 3 by 3 inches are scattered about.

A. C. Crocker Prospect (Location No. 10)

Probably a mica-quartz pegmatite, located northwest of Reed Creek Community. There are large quantities of ruled, A-structured, bent and spotted muscovite in pieces up to 4 by 5 inches, on the dump. Tangled sheets are also seen. The pit is small and caved. This prospect is quite similar to the Sam Bailey Mine. It appears to be part of a northeast trending zone of burr rock pegmatites.

Flake Mica.

General Statement: Flake mica is muscovite which is distinguished from sheet mica by grain size. Flakes are generally less than one-half inch and most commonly about one-eighth inch.

Flake mica of economic value occurs in deeply weathered, extremely inequigranular, muscovite-rich, pegmatitic granite phases of the muscovite granodiorite. The principal minerals are feldspar, (now largely kaolin) quartz and muscovite. A little biotite, (more or less leached), tourmaline and weathered garnet also occur. Muscovite flakes occur in bands of variable thickness which are alternately rich and lean. Locally partings a few feet in thickness of mica schist and what may have been biotite-plagioclase gneiss, (now dense, dike-like bodies of yellowish-brown, micaceous clay) occur in the granite.

Outcrops of mica-rich granite are sparse because of the low relief. The best outcrops are confined to gullies and artificial cuts and some information was obtained from wells. Hard rock outcrops are rare but some pavements occur. The best areas for prospecting are south of Lightwood Log Creek southwest and west of Hartwell in the northern part of the muscovite granodiorite. Specific localities which might yield economic flake mica are shown on Plate I. It seems probable that flake mica deposits will follow the general trend of the enclosing rocks but it will take detailed prospecting to establish the economic limits of any deposit.

Greyish white micaceous soils suggest the presence of flake mica deposits.

Teague and LeGrand (1947) prepared a detailed report on flake mica prospecting, properties, and processing. Included in this report are data on the Tom Myers and C. L. Lecroy properties.

Funkhouser Mica Mine

The open pit mine, Figure 27, is located one-half mile south of Hartwell. The mica-bearing granite saprolite is mined by a power-shovel. The ore is carried by truck and piled near the wet processing plant. The pile is washed with a hose and the washings are pumped into the wet plant, Figure 28. Here white clay is removed first and carried to a settling pond. Quartz, tourmaline and any remaining feldspar are removed by a Humphrey spiral. At the dry plant, Figure 29, mica is classified, dried and sacked. The flow sheet, Figure 30, shows the processing details.

Flake mica is used in roofing, paint and pipeline enamel.

Sillimanite.

General Statement: Sillimanite is widely distributed in most of the schists and gneisses, although in most places the amount is insignificant. Three types of deposits are recognized: fibrolite-quartz veins, portions of the sillimanite-graphite schists and crystalline sillimanite-mica schists. Only the crystalline sillimanite-mica schists have any immediate economic significance.

Fibrolite-quartz veins: Fibrolite occurs as a fine grained, ivory-colored, fibrous masses composed of tiny, needles of sillimanite. Masses of fibrolite occur sparsely over much of the area mapped as sillimanite-mica schists. Sporadically abundant fibrolite float occurs in an ill defined area which extends from the southern city limits of Hartwell to approximately one-half mile south of Cedar Creek. This belt extends northwestward to the Hartwell City limits near the railroad. Chunks of fibrolite ranging from pea-size to pieces a foot and one-half square are scattered about. This is best seen across the road on a low ridge east of the Funkhouser mica mine.

Sillimanite-graphite schist: The best locality for this type of sillimanite is in Bowersville, see Plate I. In weathered outcrops, the schist is buff colored with iron stained splotches, strongly foliated and contains mica, quartz and sillimanite with scattered flakes of shiny black graphite. The largest single outcrop, (about 150 feet wide across the strike) occurs on the east side of Georgia highway 17 inside the Bowersville City limits.

The following data, on two, large, partially weathered samples, were obtained by K. G. Skinner of the Bureau of Mines:

Sample Location	Weight percent sillimanite
Highway 17 within Bowersville City Limits	12
Near railroad in Bowersville	13
Estimated average grain size	100-250 mesh
Estimated graphite content	less than one percent

Sillimanite grains are coated with varying amounts of iron oxides.

The economic possibilities of the schist are uncertain. There appears to be a large size deposit with fairly constant sillimanite content which is favorable. The deep weathering and fine grain size is unfavorable.

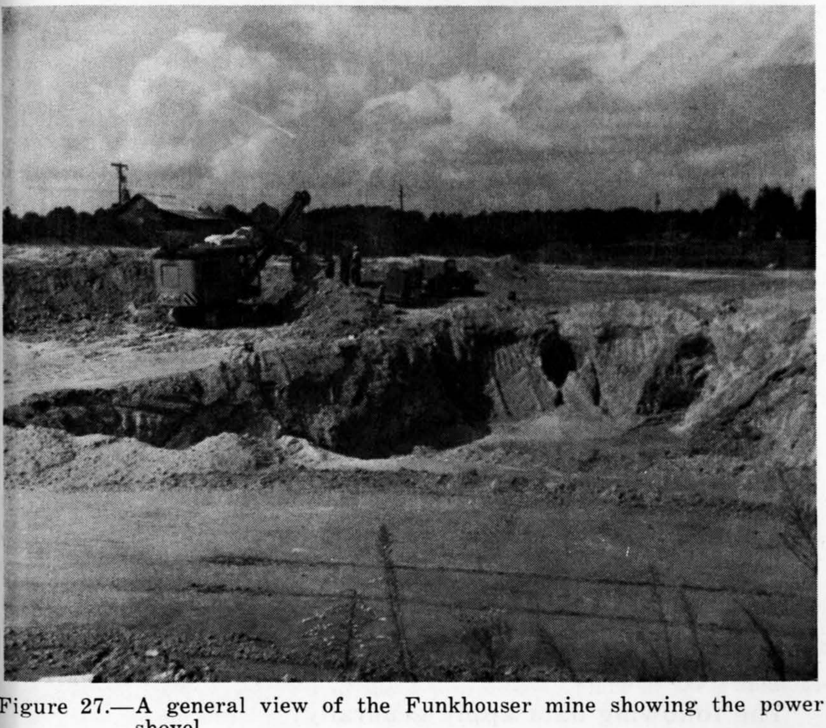

Figure 27.—A general view of the Funkhouser mine showing the power shovel.

Figure 28.—A general view of the wet processing plant at the Funkhouser mine.

Crystalline sillimanite-mica schist: With one minor exception all outcrops of crystalline sillimanite schist occur within a restricted area, shown on Plate I, southwest of Bio Church.

Fresh specimens are greyish-black with clear to greyish-cloudy match stick-shaped crystals of sillimanite ranging from tiny needle-like crystals up to 0.1 by 1.0 inches. These are set in a matrix composed of back lusterous biotite and quartz. Float specimens are usually reddish-grey-brown with sillimanite needles (usually iron stained) weathered out in relief on the foliation planes.

Individual crystals of sillimanite are square to rounded in cross section with a diagonal cleavage. The crystals are striated lengthwise because of irregular growth and the intersection of cleavage on the prism faces. Microscopic examination shows that most of the larger crystals contain inclusions of other minerals, principally quartz and biotite, Figure 7.

The following data apply generally:

Estimated average grain size of sillimanite crystals	0.5″ by 0.05″
Specific gravity of a sillimanite-poor rock	2.75
Specific gravity of a sillimanite-rich rock	2.93
Range of volume percentage of sillimanite	2 to 22 percent

The sillimanite-rich rocks occur as ledges which sometimes weather out in relief, often holding up small ridges. Ledges range in thickness from a few inches up to 30 feet with an average around five or six feet. The sillimanite content of a ledge is quite variable within a single ledge and seems to vary inversely with the amount of quartz present. Interlayered with the ledges are layers of biotite-plagioclase gneisses, biotite granite, pegmatite, amphibolitic quartzite and mica schist. The extent of the ledges along strike is difficult to estimate but some of them, judging by extrapolation between outcrops and float traces, are well in excess of 1000 feet. Ledges may occur singlely or in parallel swarms. An example of this may be seen at locality 3, Plate I. Here about 50 feet of red

Figure 29.—A general view of the dry processing plant at the Funkhouser mine.

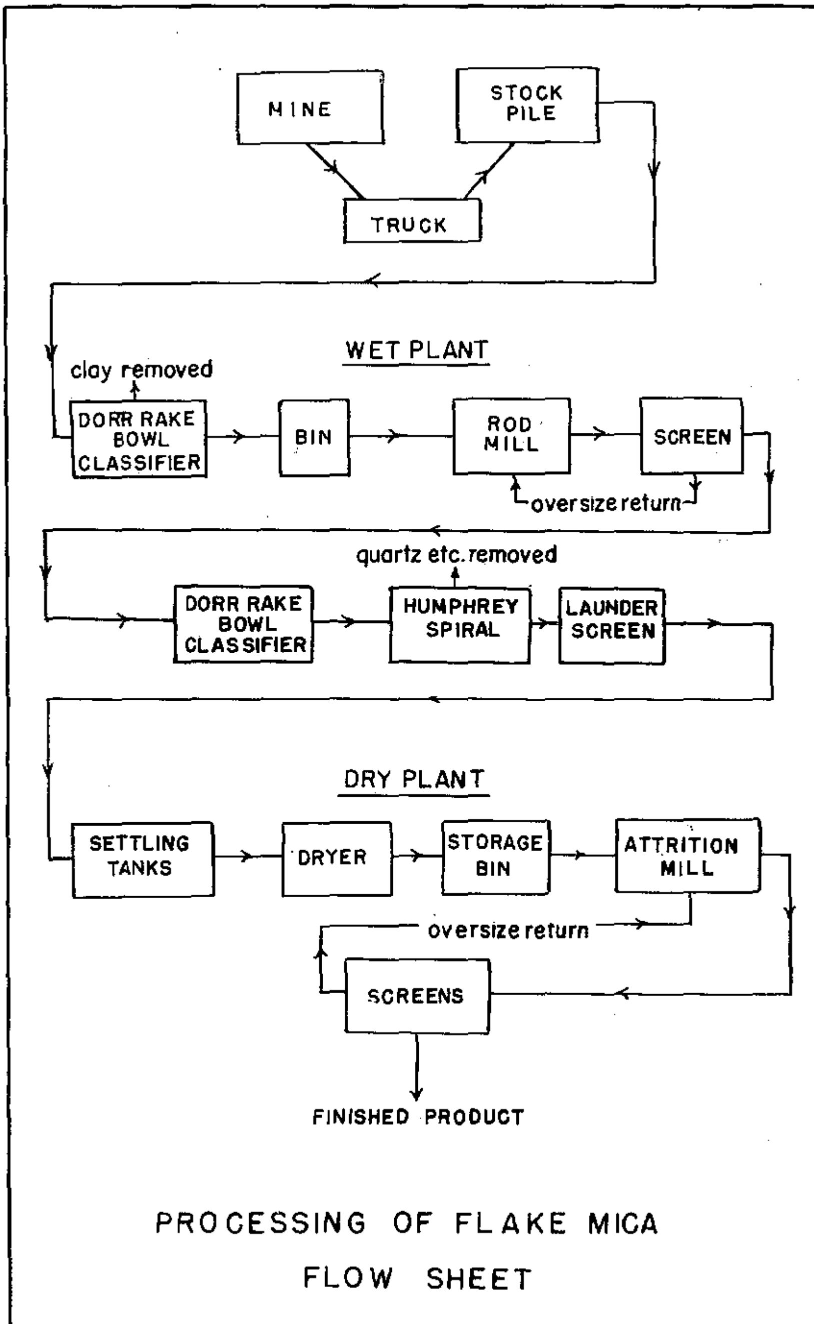
MINE
STOCK PILE
TRUCK
WET PLANT
clay removed
DORR RAKE BOWL CLASSIFIER
BIN
ROD MILL
SCREEN
oversize return
quartz etc. removed
DORR RAKE BOWL CLASSIFIER
HUMPHREY SPIRAL
LAUNDER SCREEN
DRY PLANT
SETTLING TANKS
DRYER
STORAGE BIN
ATTRITION MILL
oversize return
SCREENS
FINISHED PRODUCT
PROCESSING OF FLAKE MICA
FLOW SHEET

Figure 30

clay saprolite is exposed. The sillimanite schists occur in four distinct ledges ranging in thickness from 18 inches to 5 feet with a total thickness of 10 feet. An example of what may be a single ledge occurs at locality 4 where a ledge about 4 feet thick is exposed. In general swarms of ledges are more common. This occurrence may give an erroneous idea of the thickness of sillimanite-rich schists.

The following factors may affect the quality and the quantity of sillimanite in any given ledge:

1. Pinching out along strike.
2. Facies change along strike, this is detectable by an increase in quartz with a coincident decrease in sillimanite.
3. Alteration of silliminate to muscovite.
4. Possibly local minor shears which cause a reduction in the grain size of the sillimanite.

Jenkins Property (Location No. S_1)

This property is located on the south branch of Coldwater Creek. Sillimanite ledges outcrop intermittantly over a distance of roughly 400 feet along a steep easterly trending slope on a northeasterly trending ridge which rises sharply from the branch. Thicknesses of ledges are probably of the order of 10 or 15 feet. Granite is exposed in an old prospect pit near the junction of the branch with Coldwater Creek. The ledges dip steeply both east and west and strike about N 20° E. Ledges are also exposed in the county road to the south along strike and are presumably connected as more or less float occurs in the intervening area. Some prospecting has been done on the property.

Rice Property (Location No. S_2)

The property is located on the south side of Robinson Creek. There are no exposures of sillimanite bearing ledges. However, topographic features such as the steep easterly trending slope on a northeasterly trending ridge and abundant float with high sillimanite content suggest that this area is worthy of further prospecting.

Prospecting: The search for sillimanite may be facilitated by locating promising ledges. (A number of these are shown on Plate I). Take the dip and strike on the ledge and follow the strike across country. The trace of the rocks will usually be indicated by float and/or other outcrops. Trenching in projected areas will reveal the extent of the sillimanite.

Iron.

The deposit is located in the woods about 300 yards south of Georgia highway 51, a quarter of a mile east of the Bowersville city limits.

The old workings are covered by dense vegetation. There is an old open cut and several shafts all filled. The shafts are said to have been 50 feet deep and have, in times past, been used for burying dead mules. According to local sources the mine was worked about 35 years ago.

The ore is a limonite gossan which was probably derived from weathering of pyrite, as is suggested by its occurrence in Shoal Creek a short distance west of the mine. Float samples from the mine area analyzed by Dr. L. H. Turner of the Georgia Department of Mines, Mining and Geology contain 56.06 and 36.24 percent metallic iron.

Fragments of limonite occur in the soil over an area of roughly two square miles north and west of the mine.

The position of this area in a bend in the northeasterly trending shear zone makes possible a good site for deposition.

Quarries.

The north central part of Shoal Creek District, especially between Shoal Creek Church and Providence Church, has the best quarry sites. A few other places are indicated on Plate I as being possible sites, but none are very promising.

County Road Quarry

It is located east of the iron bridge over Shoal Creek about one-half mile northeast of Mauldins Mill.

The rock is a distinctly gneissic, grey biotite granodiorite. The banding pinches and swells irregularly. Thin lenticles of biotite schist and small pegmatites occur here and there but are very minor. Two sets of vertical joints, rather closely spaced, will limit the size of blocks which can be quarried to roughly three feet square.

In the past, the quarry has been worked for crushed rock.

Clay.

A. C. Norman Property

According to C. W. Norman there was a clay pit located between U. S. 29 and Georgia highway 8 about 1 mile east of the Nancy Hart Memorial. The pit was said to be approximately 5 acres. The operation ceased about 35 or 40 years ago. Ten men were employed and two wood burning kilns produced about 10,000 bricks per day.

The Hart County Courthouse is said to be made of yellow brick produced at this pit.

At present there is no evidence of the pit or the kilns.

Gold.

According to Jones (1909, p. 37) the gold localities belong to an isolated auriferous area outside of the major Georgia gold belts. From surface float it seems probable that all the gold prospects belong to the vein deposits and/or auriferous saprolite types of Jones (1909, p. 19). At one locality a little free sulfur occurs in cavities in vein quartz suggesting the original presence of sulfides. However, neither gold nor pyrite was seen at any of the prospects.

All of the prospecting was done over 50 years ago. The old shafts and trenches have been filled and all that is left are scattered chunks of rusty quartz.

Kings Mount Gold Mine

The mine is located a little over one mile southwest of Goldmine. According to Baker (1933, p. 287) the mine was started in 1860 following the purchase of 503 acres from James L. Brown. A plant was installed and operated until the outbreak of the Civil War. This is probably the same mine which Jones (1909, p. 266) refers to as the Brown Mine. He says, "According to reports considerable drifting was done from the main shaft on an auriferous quartz vein and a stamp mill was erected at the time the mine was operated."

The mine is now completely filled in and grown up with vegetation. Some evidence of trenches is still detectable.

The country rock is principally muscovite-biotite schist which is intruded by pegmatites and quartz veins.

Other Localities

Three old prospects are shown on Plate I. No data other than they are said to be gold prospects is available.

Jones (1909, p. 266) mentions some placer deposits between Bowersville and Royston.

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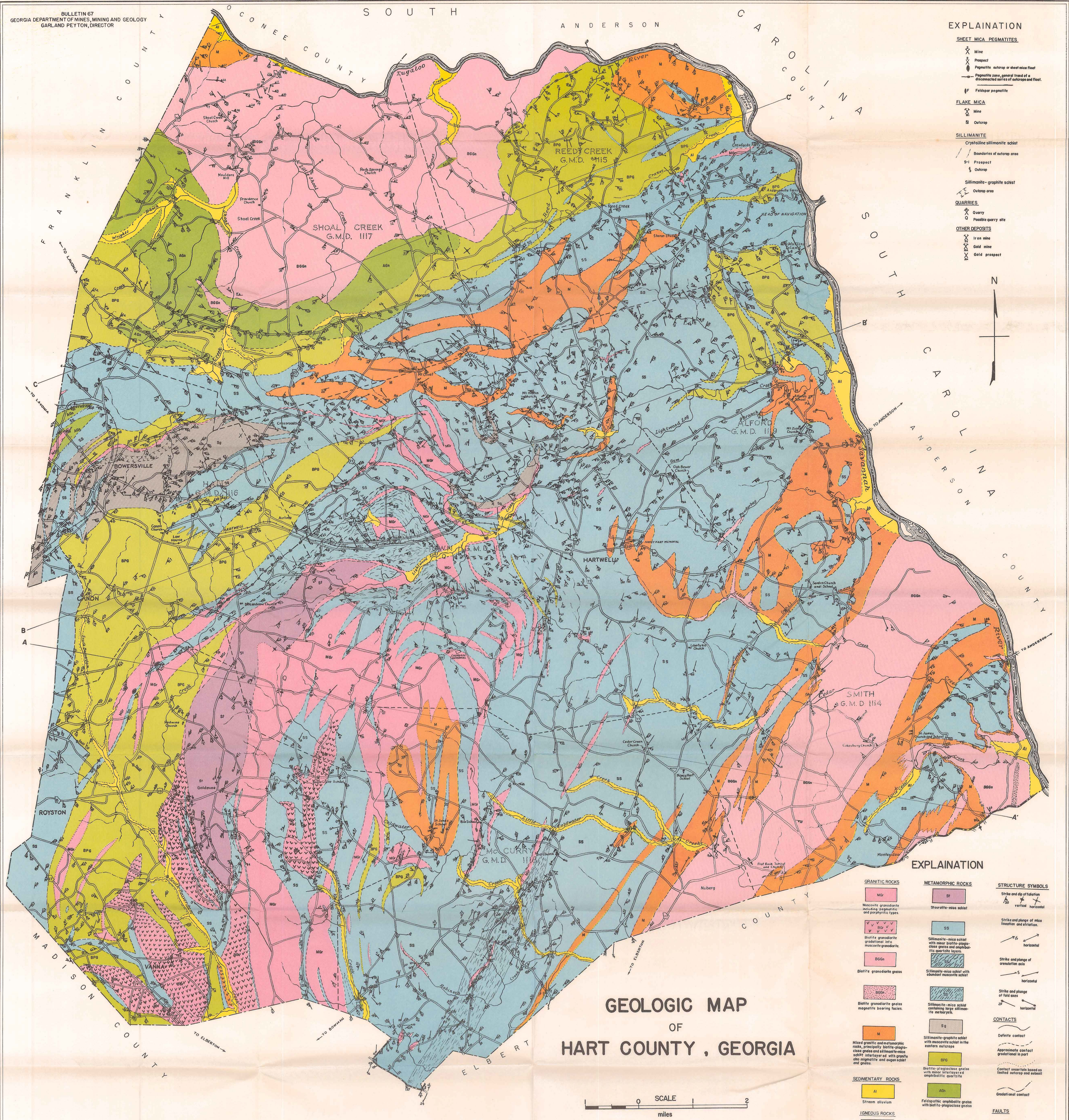
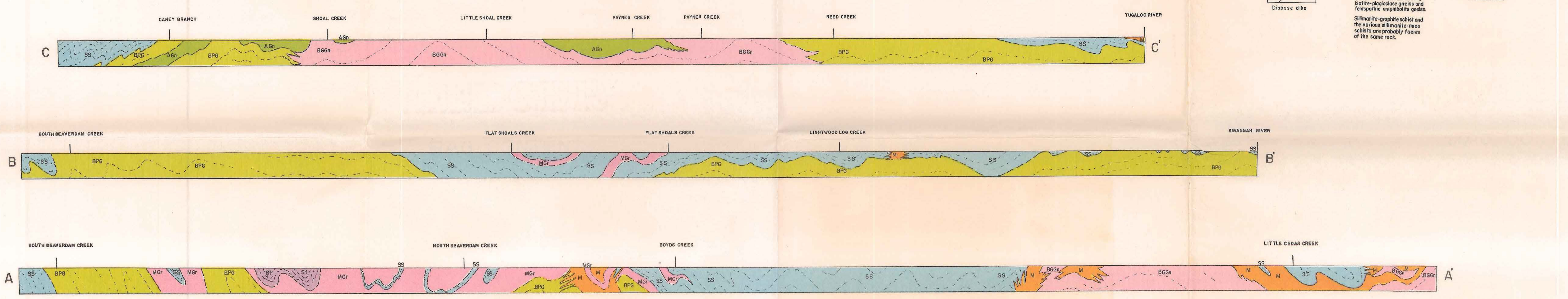


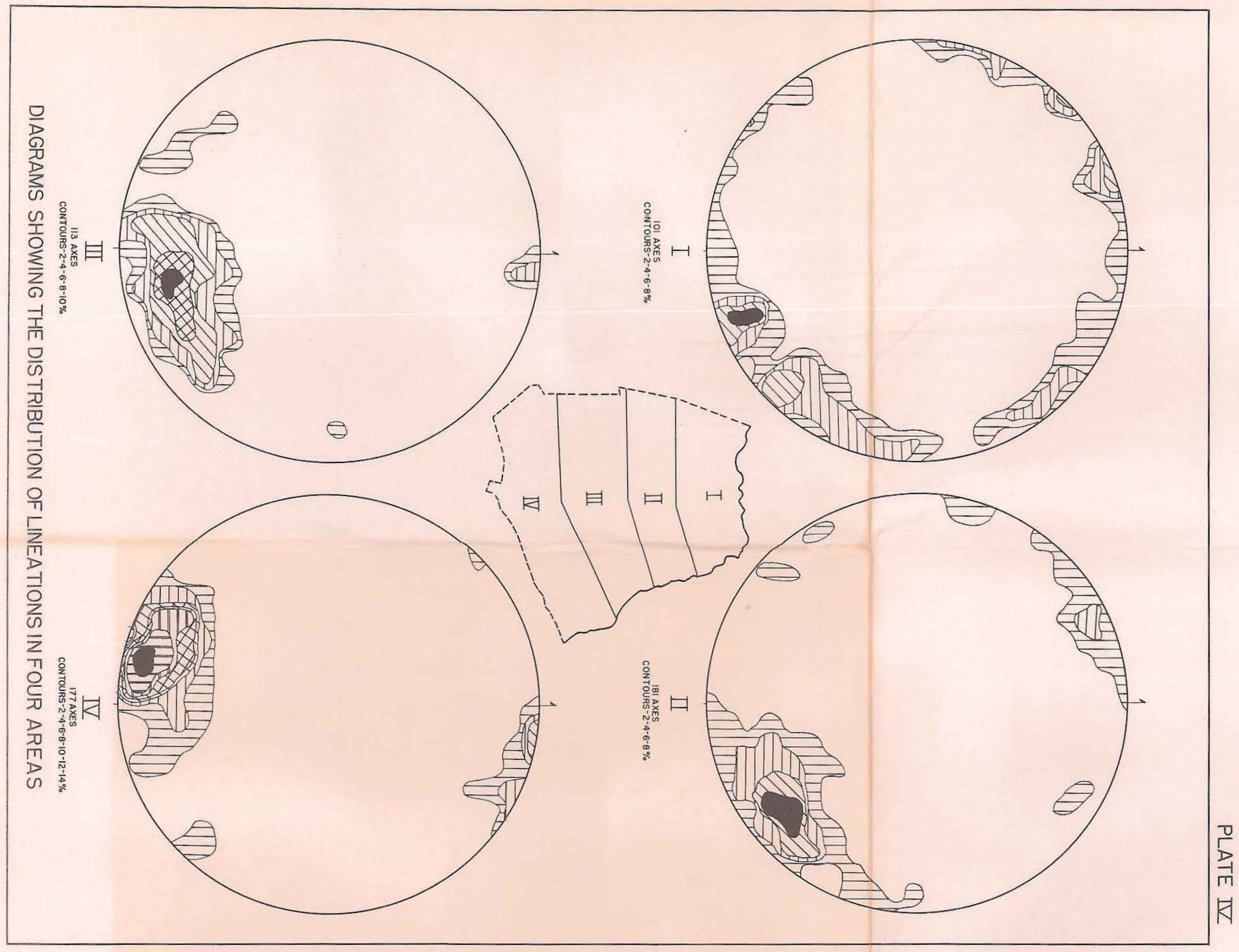


Base map by the State Highway Department of Georgia 1939

GEOLOGIC CROSS SECTIONS

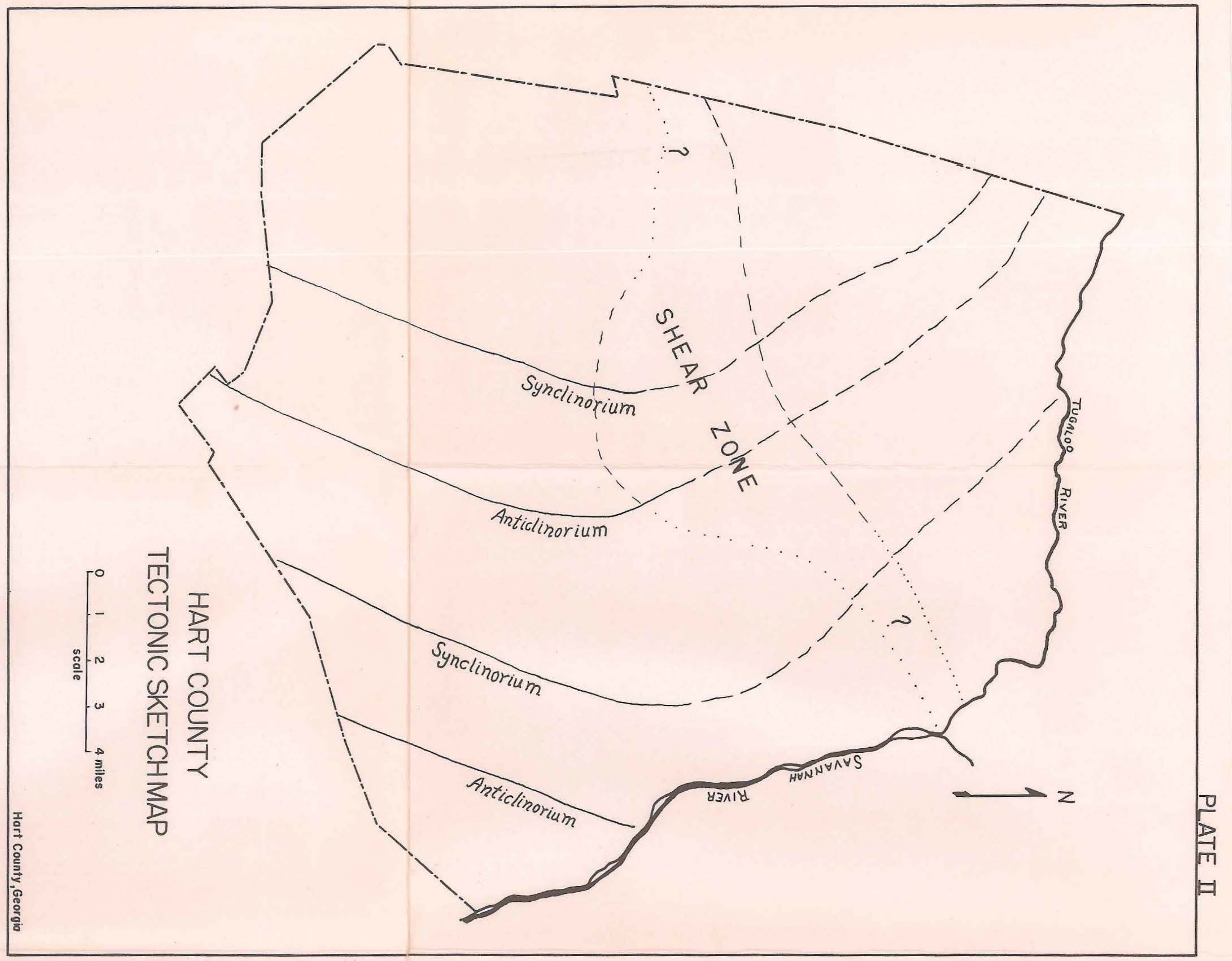
Geology by Willard H Grant 1950, 1951

PLATE IV



DIAGRAMS SHOWING THE DISTRIBUTION OF LINEATIONS IN FOUR AREAS

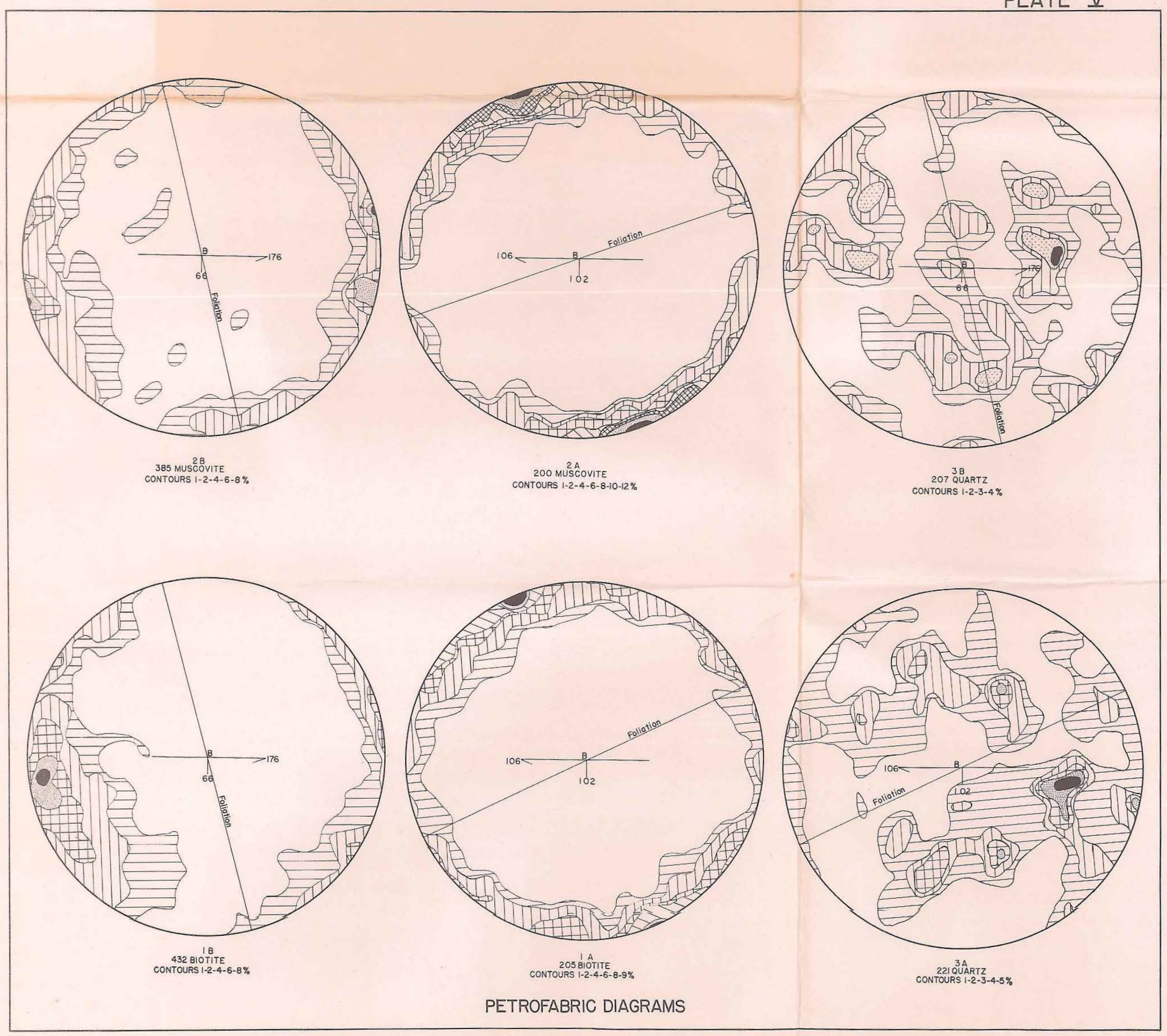
PLATE II



HART COUNTY
TECTONIC SKETCH MAP

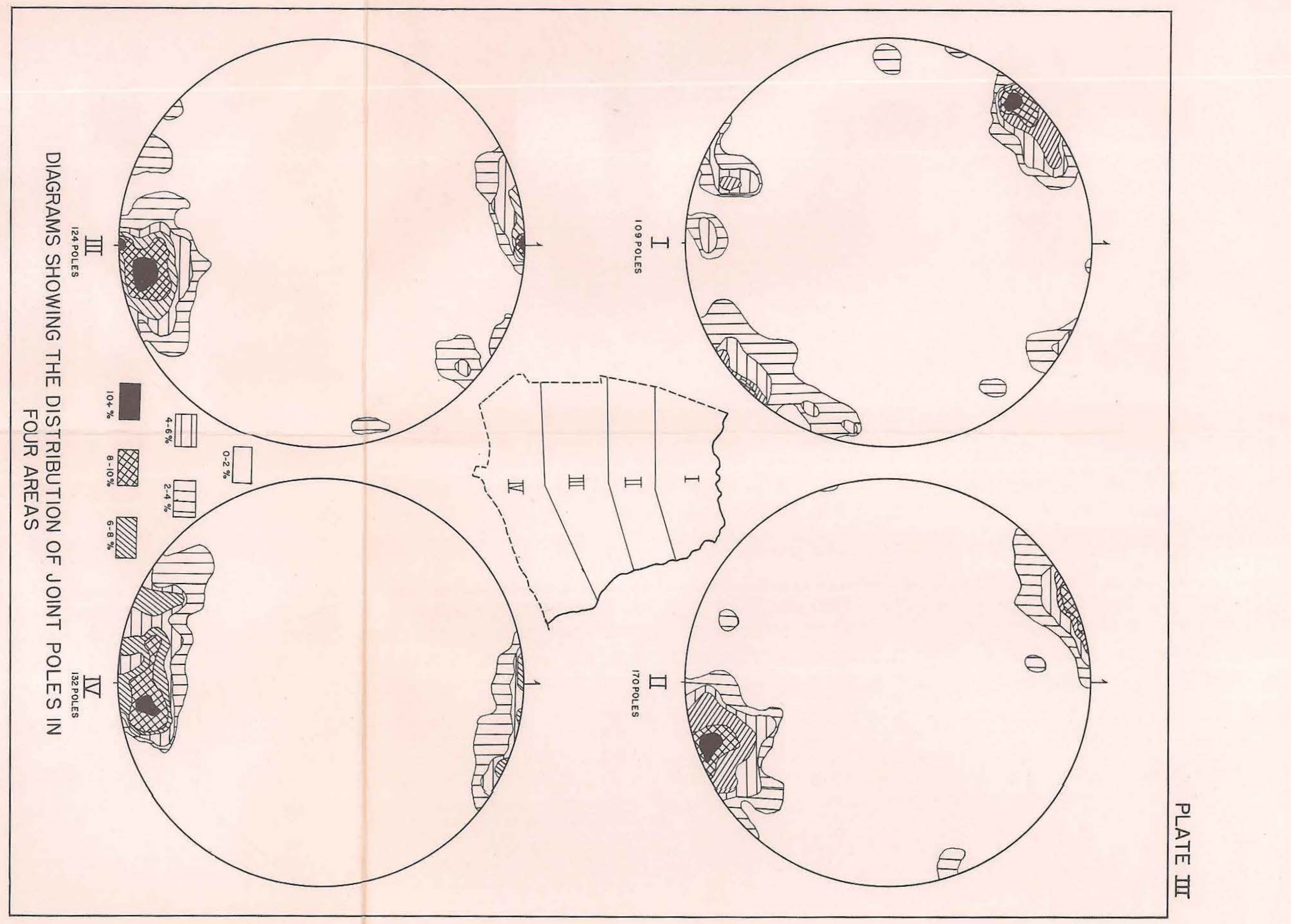
Hart County, Georgia

PLATE V



PETROFABRIC DIAGRAMS

PLATE III



DIAGRAMS SHOWING THE DISTRIBUTION OF JOINT POLES IN FOUR AREAS