GEOLOGY OF THE PLUMTREE AREA,
SPRUCE PINE DISTRICT, NORTH CAROLINA

by

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53-26

This report is preliminary and has not been edited or reviewed for conformity with U. S. Geological Survey standards and nomenclature.

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ILLUSTRATIONS

Abbreviations: O--oligoclase, A--andesine, Or--orthoclase, Q--quartz, B--biotite, M--muscovite, Chl--chlorite, Epi--epidote, Z--zoisite, H--hornblende, G--garnet, St--staurolite.

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Abstract

This report describes the results of study and geologic mapping (1:12,000) in the 70-square-mile Plumtree area in the northeastern part of the Spruce Pine pegmatite district, on the Blue Ridge upland in western North Carolina. The district has been the chief domestic source of feldspar and sheet mica. The mining belt just west of the Blue Ridge Front trends northeast and is 25 miles long and 10 miles wide. The center of the Plumtree area lies 10 miles northeast of Spruce Pine and includes parts of Mitchell and Avery Counties shown on the portions of the 7.5-minute Spruce Pine, Linville Falls, Newland, North Carolina, and Carvers Gap, North Carolina and Tennessee quadrangle.

The topography varies from rugged mountains to rounded or flat topped hills near the entrenched, meandering master streams. Old erosion surfaces are approximately 600, 1,000, 1,500, and 2,500 feet above the present master stream level. The area is in late youth or early maturity after rejuvenation.

The regionally metamorphosed rocks of the amphibolite facies form three mappable units: mica gneiss, mica schist, and hornblende rock. These rocks, perhaps of Precambrian age, are intimately interlayered with thicknesses of the individual layers ranging from less than one inch to several tens of feet. Field relationships and chemical data suggest that the mica (Carolina-type) rocks were derived from sandstones, graywackes, and shales and that the hornblende-rich (Roan-type) layers were derived from impure carbonate rocks.

The igneous rocks include alaskite and associated pegmatite of early Paleozoic age (?), dunite and associated soapstone of a prepegmatite age, and a few diabasic dikes of post-pegmatite age (Triassic?).

The alaskite and pegmatite have similar bulk compositions, notably low in iron (0.3 percent). The major constituents in order of decreasing abundance are plagioclase, perthitic microcline, quartz, and muscovite. All of these minerals, as well as clay deposits derived from the weathering of alaskite under old terraces, have economic value. The zoned pegmatites contain fewer zones which are less complex mineralogically than those in the pegmatites of many other areas. These essentially unmetamorphosed bodies were intruded approximately at the peak of the regional metamorphism. Their emplacement was controlled by local structure and rock type. The source of this igneous material may have been the mobilized portions of the Cranberry gneiss which underlies the area.

The dunite bodies were intruded early in the metamorphic cycle. The bodies are commonly zoned; from the wall rock inward (1) talc-anthophyllite-serpentine fringe, (2) serpentinized dunite, (3) granular olivine core. Dunite, chromite, vermiculite, and anthophyllite are the major economic commodities. Extensive hydrothermal alteration of dunite bodies produced soapstone.

The area is the northeast end of a southwest plunging synclinorium about 20 miles wide with the steeper limb on the northwest side. There are three structural zones: zone I on the northwest is characterized by the northeast-trending isoclinal folds with steep southeast dips; zone II on the southwest includes an area of rocks with low and variable dip; zone III is the complex central core. In the extreme northeast zones I and II have an indistinct boundary where they coalesce along the rim of the synclinorium. Six stratigraphic units are exposed totaling approximately 10,500 feet of metamorphic rocks.

Small scale structural features include a foliation, and a lineation in the planes of the foliation. Minor folding reflects the trends of the major structures. There are randomly oriented minor faults of local extent.

Introduction

Location

The Plumtree area is an arbitrary designation for the northeast portion of the Spruce Pine pegmatite district in the Blue Ridge upland of western North Carolina. The district has been the chief domestic source of feldspar and sheet mica. The producing area is a northeast-trending belt approximately 25 miles long and 10 miles wide west of the Blue Ridge Front in parts of Yancey, Mitchell, and Avery counties.

The largest towns in the district are Burnsville, Bakersville, Newland, and Spruce Pine, its commercial center on the Carolina, Clinchfield, and Ohio Railroad. U. S. Route 19E and North Carolina highways 26, 80, and 197 are the main paved highways through the district. These are supplemented by good secondary roads which make the mining district accessible. The region is drained by the Toe River and its numerous tributaries which are a part of the Tennessee River system.

The middle of the Plumtree area lies 10 miles northeast of Spruce Pine. This section is coincident with parts of the $7\frac{1}{2}$ minute Spruce Pine, Linville Falls, and Newland, North Carolina, and Carvers Gap, North Carolina-Tennessee quadrangle maps published by the U. S. Geological Survey (fig. 1).

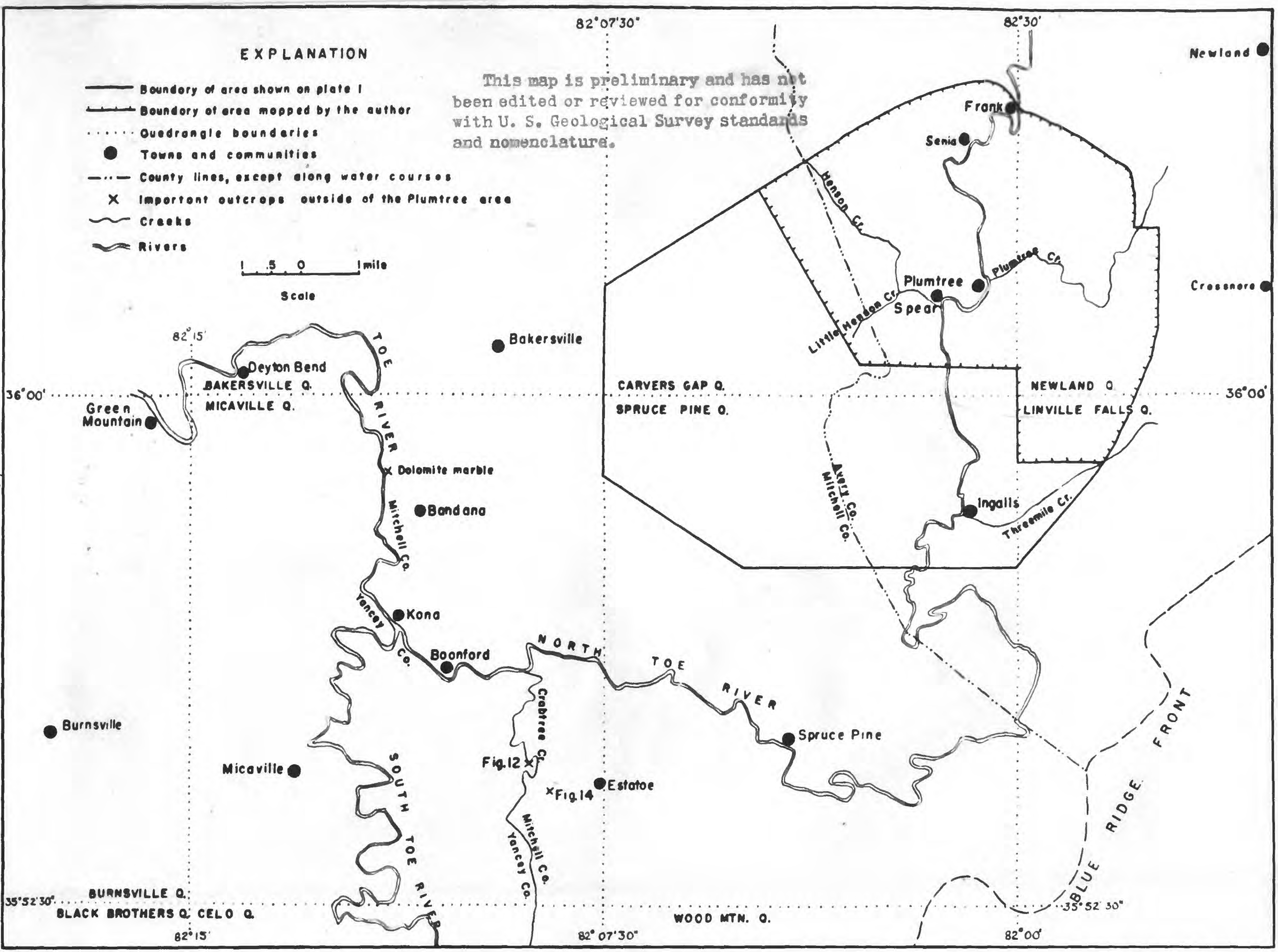


Figure 1. Index map of the Plumtree area, Spruce Pine district, North Carolina

Previous work

General geologic mapping on a small scale (1:125,000) in the Spruce Pine district and surrounding parts of the Southern Appalachians was begun by Keith (1903, 1905, 1907). No further areal studies were made in the Spruce Pine district until 1940 when detailed geologic mapping (1:12,000) was begun as a cooperative project between the U. S. Geological Survey and the North Carolina Department of Conservation and Development. The first results of this work were described by Olson (1944).

During the years of World War II, the chief mines in pegmatite were studied and mapped in detail. This information is soon to appear in an U. S. Geological Survey Professional Paper describing pegmatites in the Blue Ridge Province.

In 1948, the general geologic mapping of the district was resumed and is being continued. Parker (1953) has described some of this recent work.

Publications describing mines and various aspects of the general economic geology of the Spruce Pine district have been numerous. The following list by general subject omits those papers to which reference has already been made.

Kaolin: (Ries (1897, 1903); Watts (1913, 1914); Bayley (1925); Hunter and Mattocks (1936); Hunter (1940); Parker (1946); Stuckey (1947).

Halloysite: Hunter and Hash (1949).

Mica: Kerr (1880); Sterrett (1923); Kesler and Olson (1942); Jahns and Lancaster (1950).

Feldspar: Watts (1914); Sterrett (1923).

Chromite: Hunter, Murdock, and MacCarthy (1942).

Dunite: Pratt and Lewis (1905); Hunter and Rankin (1941).

Vermiculite: Hunter and Mattocks (1936a); Murdock and Hunter (1946).

Miscellaneous minerals: Stuckey, Hunter, and Murdock (1948).

Pegmatite: Maurice (1940).

Kyanite: Chute (1944).

Field work

The field work in the 70-square-mile Plumtree area was done in a period of eleven months during 1949 and 1950 while the author was a member of the U. S. Geological Survey party studying the Spruce Pine district. Plate 1 shows the results of the geological mapping at a 1:12,000 scale. Figure 1 indicates that part of the area mapped by the author. The southern and western parts of the Plumtree area were mapped respectively by J. L. Kulp and H. S. Johnson, Jr. in 1949 and by J. L. Kulp and D. F. Beaumont in 1950.

The discussion, however, will include information gathered in the entire Plumtree area because it is a geological unit which reveals the character of the northeast portion of the Spruce Pine district and displays geologic features typical of the whole mining belt.

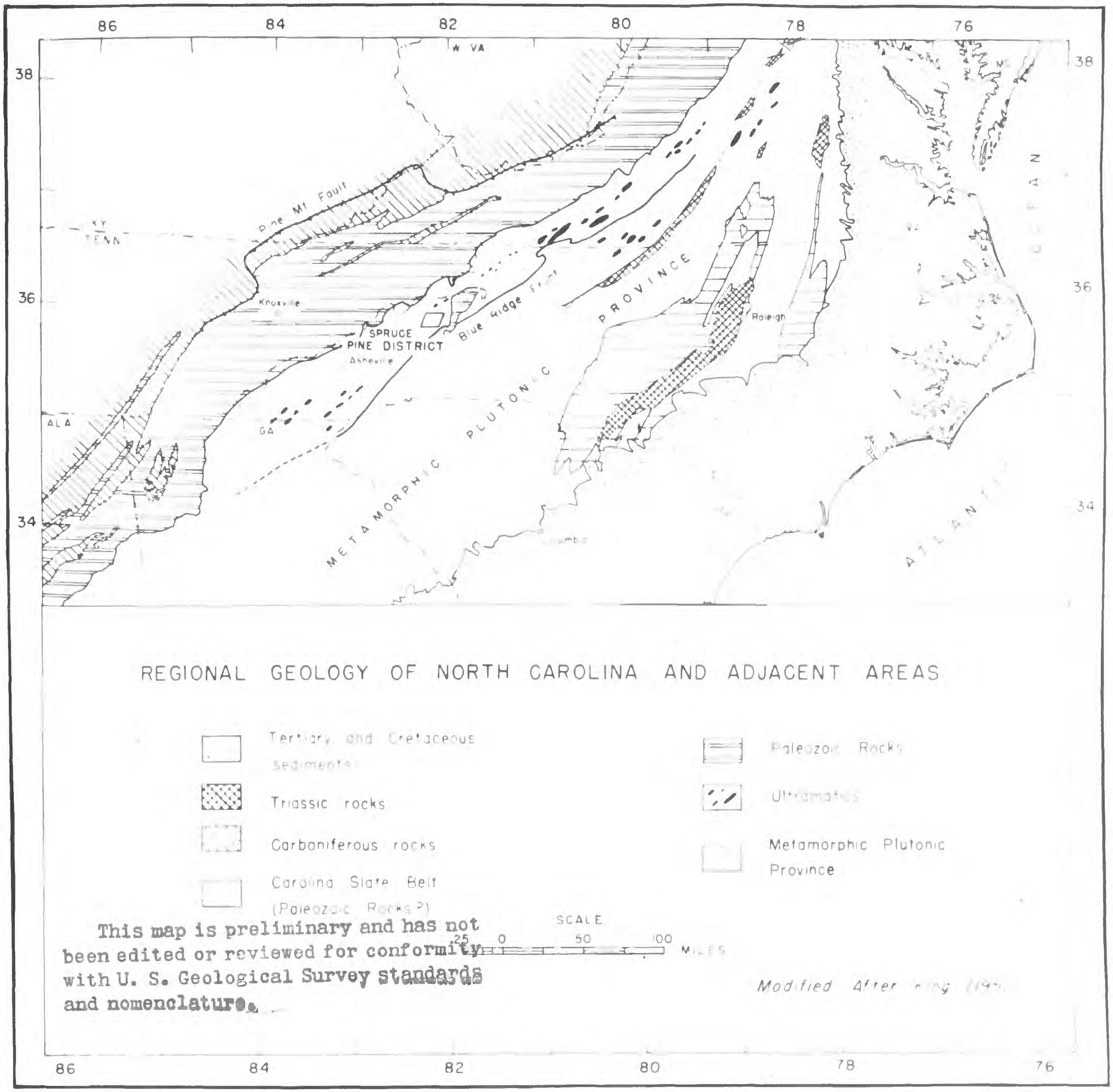
General geology

Regional setting

According to the most recent interpretation of Appalachian history and strucure (King, 1950), the Spruce Pine district lies on the west flank of the northeast-trending Appalachian geosyncline in the complexly folded core zone of gneisses, schists, and intrusive igneous rocks which make up the "metamorphic and plutonic province" (fig. 2). In North Carolina this belt is at least 100 miles wide and includes all the rocks in the Blue Ridge physiographic province and in the Piedmont physiographic province as far as the western margin of the Carolina slate belt.

Multiple and complex movements with associated igneous activity apparently continued intermittently throughout the active late pre-Cambrian and Paleozoic life of the geosyncline. Granitic rocks of various ages are widely scattered throughout the metamorphic and plutonic belt. Ultramafic intrusive bodies crudely aligned along the flanks of the geosyncline are known from New Jersey to Alabama.

Another major feature of the regional setting is the Blue Ridge Front which separates the Blue Ridge and Piedmont physiographic provinces. This 2000-foot high scarp trends approximately northeast and forms the eastern and southeastern border of the Spruce Pine pegmatite district. A detailed discussion of the scarp is outside the scope of this paper, but White (1950) considers it the results of post-Paleozoic faulting.



This map is preliminary and has not been edited or reviewed for conformity with U. S. Geological Survey standards and nomenclature.

Fig. 2

Physiography and surficial deposits

The topography of the Blue Ridge upland in the vicinity of the Spruce Pine district ranges from rugged mountains to rounded or flat topped hills near the entrenched, meandering master streams. The total impression is that of an area in late youth or early maturity after rejuvenation.

The master stream in the Plumtree area is the North Toe River, which enters the area at Frank (altitude 3,000 feet) and meanders southward through a variously narrow to one-quarter-mile-wide valley blanketed by a thin alluvial cover. The river leaves the area at an altitude of 2,700 feet just south of Ingalls. The course of the river in the Plumtree area is 11 miles with a gradient averaging 27 feet per mile.

Irregular patches of alluvium are found on the remains of terraces up to 200 feet above the present stream course. Commonly the higher alluvial deposits have been completely weathered to the point that only the quartz in the boulders and the matrix remains unaltered. Alaskite and pegmatitic alaskite bodies underlying these terraces have also been weathered to form the economically important clay deposits.

On each side of the North Toe valley in the Plumtree area is a group of north-south trending highlands. The eastern group is culminated in the north by Big Elk Ridge (altitude 4,403 feet) and in the south by Big Buck Hill (altitude 4,264 feet). The eastern highland area is drained to the North Toe River by way of Squirrel, Plumtree, and Threemile Creeks. The range west of the North Toe valley has little Yellow Mountain (altitude 5,504 feet) in the north and Big Bald Mountain (altitude 5,307 feet) in the south. Tributary drainage to the North Toe River from the west is by Roaring, Powdermill, and Henson Creeks. The west side of this range is drained by Cane Creek and many other small streams.

The relief is great in both highlands, but is greater in the western range where the difference in altitude between the mountain summits and the master stream valley may be as much as 2,000 feet in one mile, as at Spear Tops just south of Plumtree. Most of the hillsides are over-steepened, but the cover of vegetation prevents more rapid erosion.

Where vegetation has been stripped off to expose the saprolite, gully erosion is rapid. Within several months after the abandonment of lumbering or mine access trails and roads in saprolite they may be gullied to a depth of 2 to 3 feet. The land around abandoned scrap mica and clay pits soon begins to take on the appearance of "bad lands" topography. Road cuts in saprolite are in need of almost constant attention so that proper drainage of the right-of-way may be maintained.

The tributaries of the master stream usually head in steep walled, V-shaped valleys where cliffs and waterfalls are common. These valleys are generally choked with rock debris which form patchy alluvial deposits of variable thickness which coalesce with the alluvial deposits of the master stream. These alluvial covers are generally thin and bed rock commonly protrudes through them.

Effects of mass movement are evident in area. Talus slopes are common at the base of cliffs as on the south side of Powdermill Creek above Lincoln Hollow and on the west face of Mill Shoal Ridge along the North Toe River. Scars and fans resulting from landslides can be seen notably on the west face of Mill Shoal Ridge ([redacted]) 1.5 miles north of Plumtree and in the Henson Creek valley near Dellinger Hollow. Evidence of soil creep is common where fence posts and trees on steep slopes lean down hill.

A natural means of soil conservation is effected by the terraces made by grazing animals on steep pasture land. These terraces may be vertically as close as two feet with a width of one foot; they commonly follow the contour of the hill.

Essentially concordant summits in the Plumtree area can be found at approximately 600, 1,000, 1,500, and 2,500 feet above the present level of the master stream. These summit levels can be correlated with similar levels in other parts of the Spruce Pine district ([illegible]). Nearby, the monadnocks of the Black Range (Mt. Mitchell, altitude 6,684 feet) and Roan Mountain (altitude 6,285 feet) rise about 3,500 feet above the master stream.

The absolute altitude of these surfaces in the Plumtree area is obviously dependent on the altitude of the North Toe River. The absolute altitude of the various summit levels is, therefore, greater in the vicinity of Frank in the north than in the vicinity of Ingalls in the south. The lower concordant summit levels are of greater areal extent in the southern part of the area than in the north. The higher levels in the south are farther from the master stream than they are in the north.

Remnants of the surface 600 feet above the North Toe River are the summits of Slippery Hill and Mill Shoal Ridge on the Carvers Gap sheet, and Gusher Knob and Bent Ridge on the Spruce Pine sheet. Remnants of the surface 1,000 feet above the river are the parts of Doublehead Mountain with an approximate altitude of 3,800 feet, and Little Buck Hill on the Carvers Gap sheet, and Pine Knob and Hickory Flats on the Spruce Pine sheet.

Remnants of the 1,500-foot surface on the Carvers Gap sheet are the summits of Rube Green Top, Spear Tops, Cane Creek Mountain, Lightwood Mountain, Oaks Knob, Razorback Ridge, Big Elk Ridge, and Big Buck Hill. On the Spruce Pine quadrangle, the remnants are the summits of Pisgah Mountain, The Lookoff, Burleson Bald, and White Rocks.

The summits of Hawk and Little Yellow Mountains on the Carvers Gap quadrangle and those of High Knob, Big and Little Bald Mountains on the Spruce Pine quadrangle are remnants of the surface 2,500 feet above the present master stream level.

<u>Origin of land forms</u>

The five concordant summit levels and the fluviatile terraces up to 200 feet above the present level of the master streams indicate that several stages are involved in the development of the topography in this part of the Blue Ridge upland. These topographic features are the results of stream action in conjunction with regional uplift. Rejuvenation of the streams began with each uplift cycle, and resulted in dissection of the existing land surface as the river began to carve and then broaden new valleys. With repetition of this process before complete plantation of the area, the old erosion surface at higher altitude was abandoned leaving its remnants definable by concordant summit levels. In this manner, the altitude relations of the present master stream levels to the concordant summits can be explained.

The general steepness of the slopes indicates that stream erosion has not kept pace with the most recent uplift, though the vegetation cover is of importance in retarding the attainment of such an equilibrium.

The present drainage pattern with the entrenched meandering master streams certainly suggests that this pattern is inherited from a previous erosion cycle. This premise is based on the fact that the meanders are neither restricted to areas of saprolite nor controlled by the complex structure of the area.

The mass movement phenomena described in the previous section have several noteworthy aspects. The main factors contributing to soil creep and potential landslide are the climatic conditions, the presence of extensive saprolite, and the steep slopes. The 60 to 70 inches of rainfall annually are received rather evenly over the year. During the summer heavy showers are the rule. During the winter soaking rains lasting several days, as well as daily alternations of freezing and thawing are common. The saprolites thus developed are capable of absorbing much moisture, which increases their weight per unit volume and acts as a lubricant between the grains, especially in the micaceous saprolite. On steep slopes the weakened saprolite may give way easily to mass movement.

Petrology and petrography

The Spruce Pine district is underlain by a metamorphic complex intruded by alaskite (a plutonic rock characterized by alkali feldspar and quartz with little or no dark component (Spurr 1900), pegmatitic alaskite, diabase, and ultramafic rocks. The metamorphic rocks are chiefly mica and hornblende gneisses and schists. Associated with these rocks are quartzite, dolomite marble, and layers rich in actinolite, diopside, epidote, zoisite, chlorite, and feldspar. Soapstone has been derived by the alteration of ultramafic rock.

All of these rock types, except the dolomite marble, crop out in the Plumtree area. Petrographic examination of samples from other parts of the Spruce Pine district indicate that the rocks of the Plumtree area are typical of the mining district as a whole. The following rock descriptions are based on the study of 200 thin sections.

Metamorphic rocks.

For purposes of mapping, the metamorphic rocks were divided into three units: (1) mica gneiss, (2) mica schist, and (3) undifferentiated hornblende rocks. The small amounts of quartzite, chlorite, actinolite, diopside, zoisite, and epidote rocks which do not form mappable units were included with the main rock type of the immediate vicinity. The quartzite, chlorite, and epidote rocks may occur within either the mica or hornblende units, but the actinolite, diopside, and zoisite-rich layers are found generally with the hornblende rocks.

Keith (1903, 1905, 1907) separated these rocks into two mappable units of Archean age, the Carolina gneiss (mostly mica gneiss and schist of sedimentary origin) and the Roan gneiss (mostly hornblende gneiss and schist of intrusive igneous origin). These formations have been mapped widely in the Blue Ridge and Piedmont of the Southeast, so widely in fact that it has become doubtful that the terms Carolina and Roan are useful formation names. It is agreed with Kesler (1944) that the terms should be used only in a compositional sense, because the age and origin implied by Carolina and Roan may not necessarily apply over a region extending from Maryland to Alabama. For this reason the mica gneiss and schist units may be called Carolina-type rocks, and the various hornblende gneisses and schists may be called Roan-type rocks.

G. W. Stose and A. J. Stose (1949, p. 315) have used the name Lynchburg gneiss for the entire sequence of hornblende and mica rocks in the region around Spruce Pine. The results of this study indicate that the use of Lynchburg gneiss in this area is inappropriate for several reasons (see p.).

Near the northwestern and eastern borders of the area there are highly feldspathic layers typical of the banded light colored gneisses mapped by Keith (1903, 1907) in areas of Cranberry granite and gneiss. The nearest areas mapped as Cranberry lie approximately 2 miles from the edges of the area mapped in this study.

All of these rocks are intimately interlayered; the individual layers range in thickness from less than one inch to several tens of feet, but rarely does a single outcrop expose only one rock type. Because of this intimate interlayering it should be understood that the units mapped on plate 1 indicate the most abundant rocks of the sequence in any given place (table 1 and fig. 5).

Lateral and vertical gradations exist between the rocks of the mappable units. A lateral gradation between mica gneiss and mica schist can be traced from the south slopes of Long Level Mountain eastward across Doublehead Mountain to Pine Ridge, just south of Plumtree Creek (pl. 1). The vertical gradations generally take place by gradual increase in layers characteristic of one unit over those of another.

Figure 5. An outcrop illustrating the intimate interlayering of rocks with different mineral composition. This is the outcrop of the hornblende rock unit in the bed of Plumtree Creek from which the data on Table 1 was gathered. The 6-inch quartzite bed (marked Q) was the base of the measured section. The distribution of the mineral components in the various layers is not regular, suggesting the possibility that this heterogeneous arrangement is a result of graded bedding.

Table 1

A. Summary of measurements made across a contact between the mica gneiss and hornblende rock unit along the road near altitude 3,118 in the Henson Creek Valley.

Rock type	Number of layers	Total thickness in inches	Percent of rock in section
H-F gneiss	22	197	26
F-Q-B gneiss	10	45	6
B-M schist	7	39	5
F-Q-B-M gneiss	25	326	43
F-Q-M-B gneiss	2	30	4
M schist	4	34	4
Q-F-M schist	2	44	6
H-quartzite	1	1	-
Quartzite	1	30	4
Pegmatite	2	18	2
	76	764	100

B. Summary of measurements made on a section of undifferentiated hornblende rocks in the bed of Plumtree Creek, near altitude 3,450 feet.

Rock type	Number of layers	Total thickness in inches	Percent of rock in section
H schist	7	4	6
H-Q schist	2	2	3
H quartzite	1	1	2
H-F gneiss	3	11	17
H-F-Q gneiss	3	12	19
H-F-B-M gneiss	1	3	5
F-Q-H-B-G gneiss	3	11	17
F-Q-H-B gneiss	2	4	7
F-Q-B-H-G gneiss	4	9	15
Quartzite	1	6	9
	27	63	100

(H-hornblende, F-Feldspar, Q-quartz, B-biotite, M-muscovite, G-garnet.)

Mica rocks of the Carolina-type

The fresh mica rocks are gray with a shade of blue, green, or brown, depending on the mineral composition and the distribution of the minerals within the individual layer. The grain size ranges between 0.1 and 5 millimeters. The structures are schistose to gneissic and the textures are granoblastic to lepidoblastic.

The chief constituents are plagioclase, quartz, biotite, and muscovite. Other minerals include garnet, staurolite, kyanite, orthoclase, epidote, allanite, apatite, zircon, sphene, rutile, chlorite, hornblende, carbonate, magnetite-ilmenite, hematite, pyrite, and pyrrhotite. Organic matter may also be present.

Mica gneiss

The individual layers of mica gneiss appear homogeneous because the constituent minerals are evenly distributed throughout the layers which are hard and do not break easily. Foliation is generally less distorted than in the schists. The constituent minerals are those listed in the previous section (p. 17). The grain size of the gneisses ranges between 0.1 and 3 millimeters, with the porphyroblasts of garnet, staurolite, kyanite, and plagioclase as large as 5 millimeters across the largest dimension.

The mica gneisses and all of the other metamorphic rocks are named for their chief mineral constituents. Any mineral in amounts of 10 percent or more is considered a "chief constituent". Among 42 samples of mica gneiss studied in this section, 12 varieties were found:

O-Q-B
O-Q-B-M (with or without garnet)
O-Q-B-St
O-Q-B-Epi
O-B-Q-M
O-B-Q-G
O-B-Q-Or
O-B
O-M-B-Q (with or without garnet)
O-G-Q
Or-Q-B-O
Q-O-M-B

(O-oligoclase, Q-quartz, B-biotite, M-muscovite, St-staurolite, Epi-epidote, Or-orthoclase.)

The modes of mica gneisses are listed in table 2; chemical analyses are given in table 6.

The oligoclase-quartz-biotite-gneisses form about 60 percent of the mica gneiss unit, the oligoclase-biotite-quartz gneisses make up 20 percent, the oligoclase-muscovite-biotite-quartz gneiss, which is a large part of the gneiss transitional to the mica schist, is 15 percent, and the remaining rock types are 5 percent of the unit.

Table 2

Modes of mica gneiss

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Plagioclase	48	35-60	37	27-50	48	33	45	46	57	40	50	25	50	15
An of plagioclase	24	20-30	26	25-30	26	24	30	28	23	23	23	28	25?	30
Quartz	25	15-35	20	15-30	17	15	15	21	5	15	10	45	20	25
Biotite	18	10-25	20	15-20	25	15	15	20	25	20	25	10	2	15
Muscovite	3	tr-3	15	10-20	6	23	5		3	3	tr	20		2
Garnet	2	0-10	2	0-10	1	7	tr		3	20			20	
Magnetite) Ilmenite)	1	tr-5	3	tr-5	1	5	5		2	tr			2	
Epidote	2	0-7	2	0-5	tr	1	1	10	3		3			3
Apatite	tr	0-3	tr	tr-3	1	tr	2	2	1	tr	tr			1
Zircon	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	
Chlorite			tr	0-tr		tr	1			tr				
Sphene					tr						tr	tr		1
Rutile								tr		tr				
Staurolite							10						5	
Kyanite										tr				
Orthoclase											10			25
Calcite														2
Pyrite											tr			8
Organic matter														2

1. O-Q-B gneiss, average of 19 samples.
2. O-Q-B gneiss, range of 19 samples.
3. O-B-Q-M gneiss, average of 6 samples.
4. O-B-Q-M gneiss, range of 6 samples.
5. O-B-Q gneiss, average of 6 samples.
6. O-M-B-Q gneiss, average of 2 samples.
7. O-Q-B-St gneiss from Long Level Mountain, Avery Co.
8. O-B-Q-Epi gneiss from Doublehead Mountain, Avery Co.
9. O-B-Q gneiss, average of 2 samples.
10. O-B-Q-G gneiss from Doublehead Mountain, Avery Co.
11. O-B-Q-Or gneiss from Doublehead Mountain, Avery Co.
12. Q-O-M-B gneiss from Doublehead Mountain, Avery Co.
13. O-G-Q gneiss from Long Level Mountain, Avery Co.
14. Or-Q-B-O gneiss from Little Hanson Creek valley, Avery Co.

(O-oligoclase, Q-quartz, B-biotite, M-muscovite, St-staurolite, Epi-epidote, Or-orthoclase, G-garnet, tr-traces.)

The mica gneiss weathers to a brown or red-brown soil characterized by fine flakes of silvery white hydromica and small quartz grains. Rubbing the soil in the hand generally produces a gritty "feel". The darkness of the soil color is partly a function of the amount of biotite in the parent rock, but the color intensity is also increased with an increase in moisture content to such a degree that the mica gneiss soils may be confused with those derived from the biotitic hornblende rocks or even red soils derived from the common biotite-free hornblende rocks. The hydromica flakes tend to be scattered over the ground surface by rain, a check of the soil an inch or two beneath the surface will usually reveal the true character of the parent rock.

Mica schist

The individual layers have a heterogeneous appearance because the distribution of the mineral constituents is irregular. Commonly a wavy appearance is found when quartz and feldspar pods or discontinuous streaks are separated by thin layers of mica. Foliation is generally more distorted than in the gneisses. The grain size of the mica schists ranges from 0.5 to 5 millimeters, though some porphyroblasts of garnet, staurolite, and kyanite may have a long dimension as great as 1 centimeter.

Mineralogically, the mica schists are similar to the mica gneisses and the following varieties were found:

O-B-Q (with or without garnet)
O-B-Q-M (with or without garnet)
O-B-M-Q (with or without garnet)
O-Q-B-M
O-Q-M-B
O-M-Q-B (with or without garnet)
M-O-B-Q
M-Q-G
B-M-Q-O-G
B-O-Epi
Q-M-O-B (with or without garnet)
Q-M-B-O
Q-M-B
Q-O-M
Q-M-Chl-O

(O-oligoclase, B-biotite, Q-quartz, M-muscovite, G-garnet, Epi-epidote, Chl-chlorite.)

The modes of typical mica schist are listed on table 3 and chemical analyses are shown on table 6.

The estimated abundance of rock types within the mica schist can be summarized as follows: 40 percent is schist dominated by muscovite and biotite, 40 percent is schist dominated by oligoclase, and 20 percent is schist dominated by quartz. The schists transitional to the mica gneiss are mostly from the group with predominant oligoclase.

The mica schist weathers to a brown soil characterized by mica flakes or books as large as 3 millimeters across the long dimension of the basal plate. The soil also contains pods of quartz or feldspar of similar size which are generally surrounded by mica. The mica schist soils are distinctive and not easily confused with soils derived from the other rock types in the area.

Table 3

Modes of mica schist and quartzite

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Plagioclase	48	38	40	35	40	38	25	10	32	20	10		20	10	3
An of plagioclase	27	23	28	23	32	28	23	25	24	22	26		25?	27?	20
Quartz	15	15	10	27	25	17	15	20	2	40	50	55	60	30	93
Biotite	25	26	15	20	10	15	20	15	40	10	15	15	5		2
Muscovite	2	13	15	15	15	20	30	35	5	25	20	25	10	25	1
Garnet	5	4	10		5	7	4	20		2		3	2		
Magnetite) Ilmenite)	1	1	2		2	2	3		tr	2	2		1		
Epidote	2		2	tr	tr	tr	tr		20		2				
Apatite	tr		tr	2	2	tr	2			tr		1	1	2	
Zircon	tr		tr	tr		tr	tr		tr	tr	tr	tr	tr	tr	tr
Chlorite		tr	3			tr					tr			25	
Rutile														1	1
Kyanite														3	
Staurolite		2	2			tr								3	

1. O-B-Q schist, average of 6 samples.
2. O-B-Q-M schist from southwest of Richs Gap, Avery Co.
3. O-B-M-Q-G schist from Cane Creek Mountain, Mitchell Co.
4. O-Q-B-M schist from Mill Shoal Ridge, Avery Co.
5. O-Q-M-B schist from Little Henson Creek valley, Avery Co.
6. O-M-Q-B schist, average of 6 samples.
7. M-O-B-Q schist from near Richs Gap, Avery Co.
8. M-Q-G-B-O schist from Doublehead Mountain, Avery Co.
9. B-O-Epi schist from Middle Elk Ridge, Avery Co.
10. Q-M-O-B schist from near Plumtree, Avery Co.
11. Q-M-B-O schist from Spear, Avery Co.
12. Q-M-B-O schist from Little Henson Creek valley, Avery Co.
13. Q-O-M schist from Middle Elk Ridge, Avery Co.
14. Q-M-Chl-Or schist from Doublehead Mountain, Avery Co.
15. Quartzite from Doublehead Mountain near Spear, Avery Co.

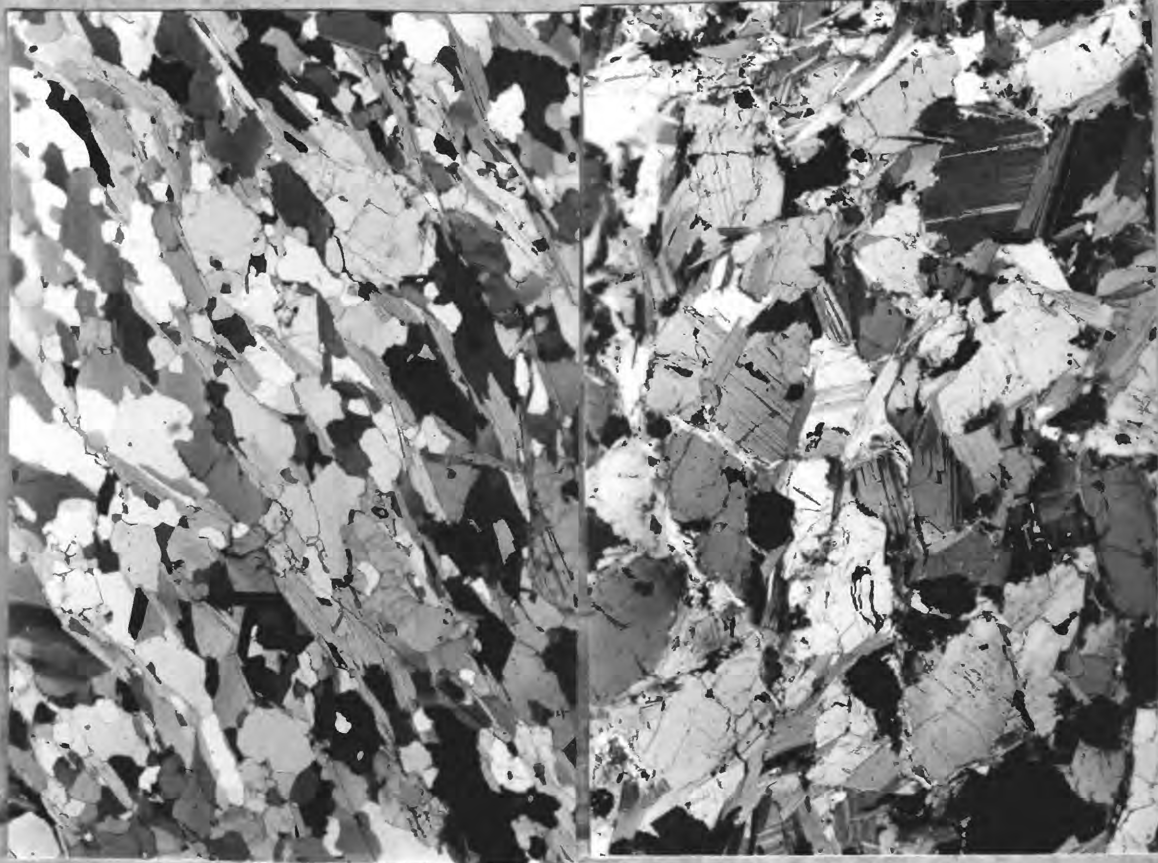
(O-oligoclase, B-biotite, Q-quartz, M-muscovite, G-garnet, Epi-epidote, Chl-chlorite, Or-orthoclase, Tr-traces.)

Petrography of the Carolina-type rocks

Structure and texture.--Plate 2 A illustrates the texture of the widespread and common oligoclase-quartz-biotite gneiss. The foliation is undistorted and the minerals are evenly distributed throughout the sample. In plate 2 B equidimensional oligoclase grains are surrounded and cut at places by mica grains giving a "brick and mortar" texture to the rock. Granulation of a rock like that shown in plate 2 B yields a finer grain size and causes splintering and smearing of the mica "mortar" (pl. 3 A). The mica gneisses may also be dense, fine-grained rocks (pl. 3 B) with an average grain size of 0.25 millimeter with scattered porphyroblasts of mica (1.5 millimeters long) and epidote (0.5 millimeter longest dimension).

A transition occurs between the mica gneiss and schist; the grain size increases, mica becomes more abundant and distorted foliation more apparent in the schists. The texture of a transitional mica rock is illustrated in photograph A (pl. 4).

The typical mica schist texture is shown in plate 4 B. Notice the distorted mica, the garnet porphyroblasts, and the lenses of quartz and oligoclase. The mica schists may have their foliation worked into tiny chevron folds with less than 1 centimeter from crest to crest. Plate 5 A illustrates the crest of a chevron fold as seen in thin section. Plate 5 B shows characteristic texture of the coarse-grained mica schists which do not have distorted foliation.

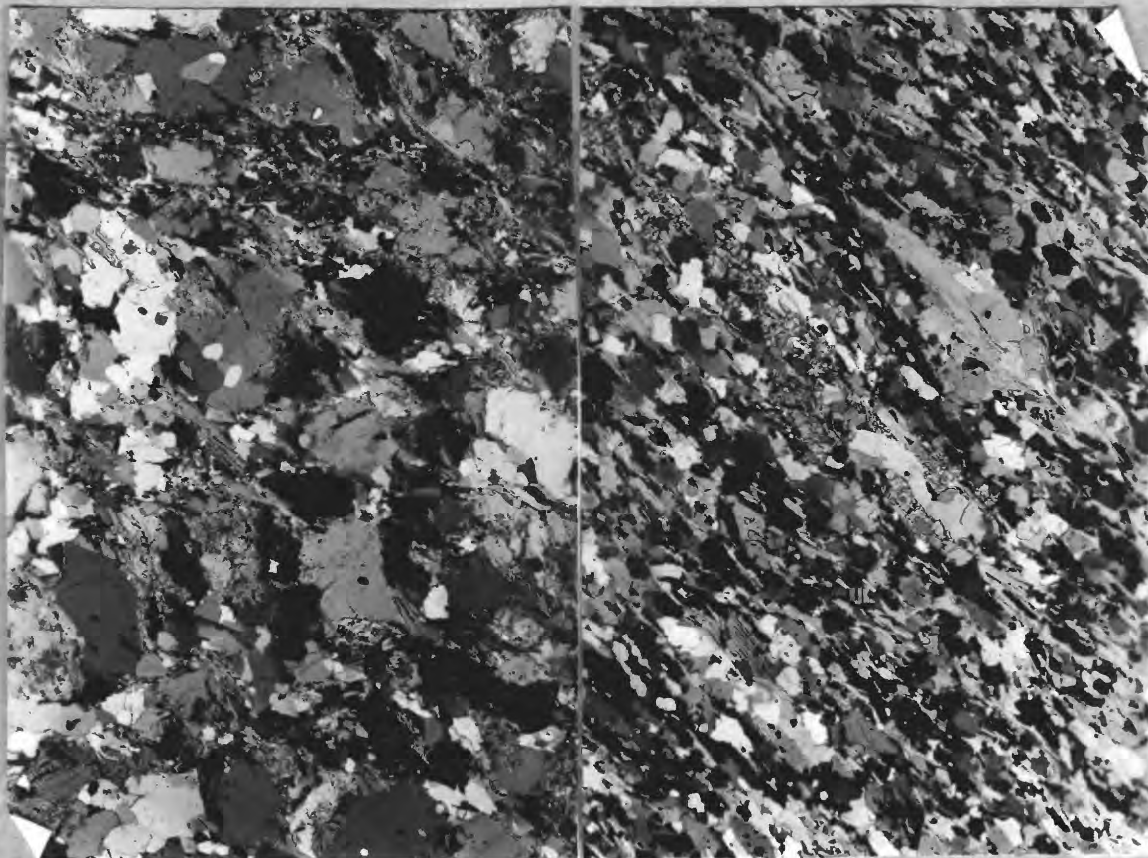


A B

Plate 2

A. Oligoclase-quartz-biotite gneiss (X 16, X nicols) showing the typical texture and structure of this widespread and common mica gneiss. The large grains are about 1 millimeter across the longest dimension. Note the even distribution of the biotite, quartz, and plagioclase of which much is untwinned. Locality: near the junction of the Plumtree Creek road with U. S. route 19E north of Plumtree.

B. Oligoclase-biotite gneiss (X 16, normal light). Biotite filling the interstices of the albite-twinned oligoclase to produce a "brick and mortar" texture. The interstitial position of the biotite suggests that the biotite formed after the feldspar. The oligoclase grains average 1 millimeter across the largest dimension. Locality: Cane Creek Mountain, Mitchell Co.

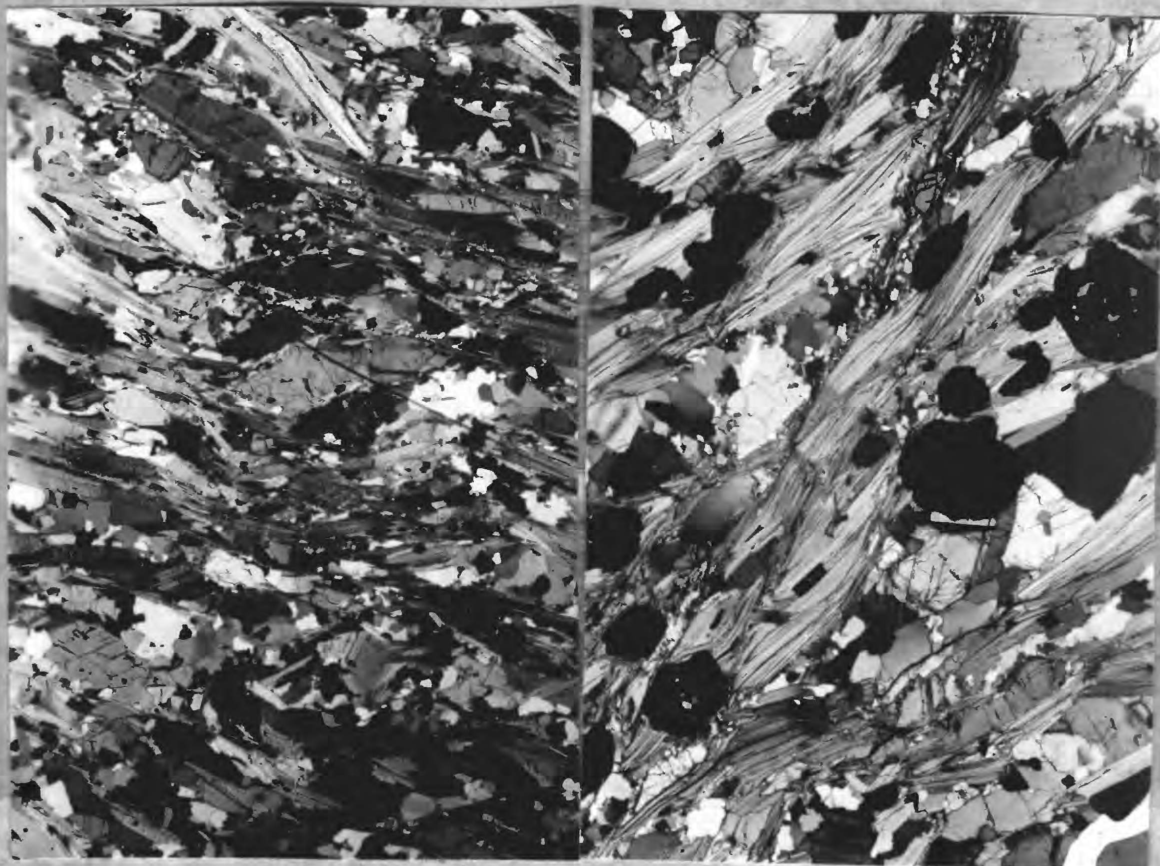


A B

Plate 3

A. Oligoclase-quartz-biotite gneiss (X 16, X nicols). A distorted gneiss fabric with smeared biotite interstitial to quartz and untwinned oligoclase. The feldspar grains are 1 millimeter across the longest dimension. Locality: Charlies Ridge, Avery Co.

B. Orthoclase-quartz-biotite-oligoclase gneiss (X 16, X nicols). The biotite porphyroblast in the upper right is 1.5 millimeters long and the epidote grains (high relief) in the center, extending diagonally from upper left to lower right, are 0.5 millimeter long. The orthoclase, twinned oligoclase, quartz, and opaque pyrite and organic matter are the bulk of the fine-grained (0.25 millimeter) material. Locality: Little Henson Creek valley, Avery Co.

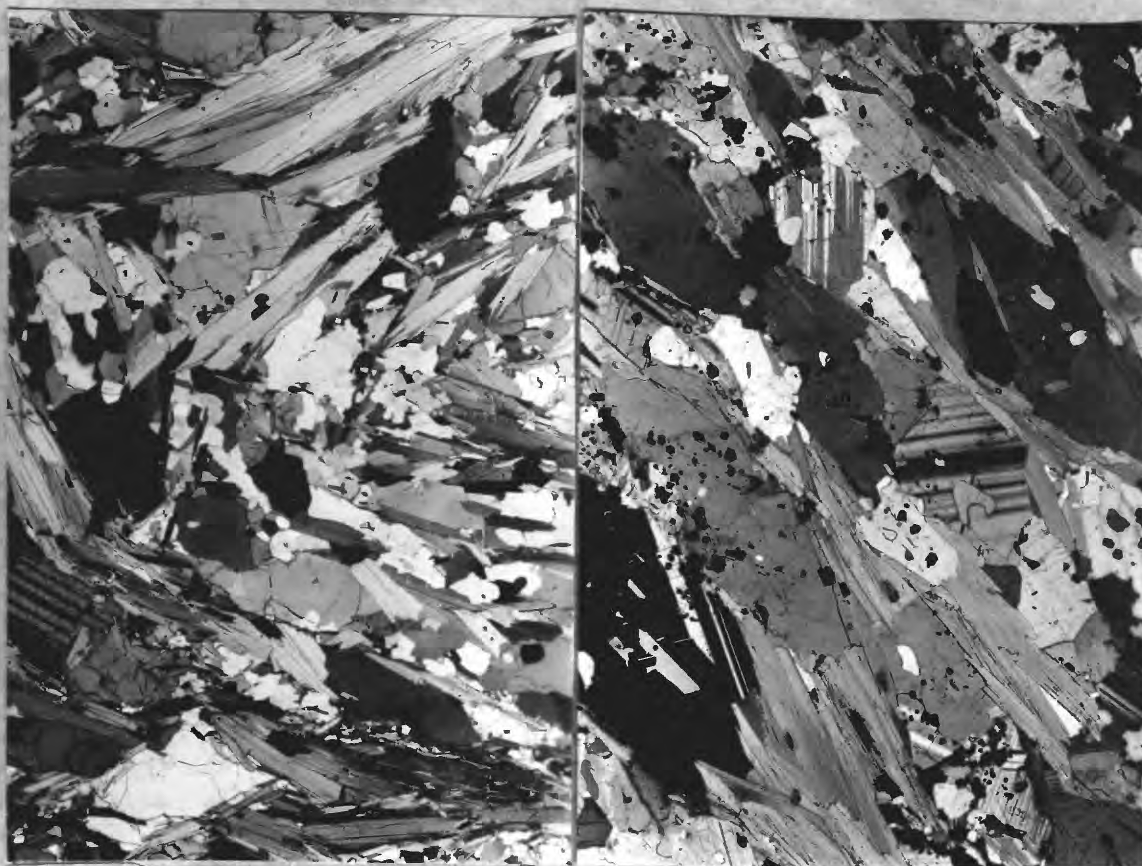


A B

Plate 4

A. Oligoclase-muscovite-biotite-quartz gneiss (X 16, X nicols). This gneiss illustrates the textural features characteristic of the transition from mica gneiss to mica schist—the greater abundance of mica and the segregation of the mica, plagioclase, and quartz which is more typical of the mica schist. In the center of the photograph is a crushed plagioclase porphyroblast. Fine mica, quartz, and plagioclase fill the interstices of the larger oligoclase grains. The deformation of the porphyroblast has produced a flaser structure. Locality: Cane Creek Mountain, Mitchell Co.

B. Oligoclase-muscovite-quartz-biotite-garnet schist (X 16, X nicols) is a common variety of mica schist. It displays the features typical of the schists, abundant 2 millimeter long mica books separating quartz streaks (left center) and poorly twinned oligoclase streaks (right center). The quartz in the left center of the picture is granulated and has undulatory extinction. Subhedral to euhedral garnets (the prominent dark grains actually 0.5 to 1 millimeter across) are well distributed. Locality: Cane Creek Mountain, Mitchell Co.



A B

Plate 5

A. Muscovite-oligoclase-biotite-quartz schist (X 16, X nicols) illustrating the small tight chevron folds found in some of the mica schists. The black line indicates the trace of the axial plane across the photograph. In this sample, the distance from crest to crest of the folds is about 7 millimeters. Locality: near Richs Gap, Avery Co.

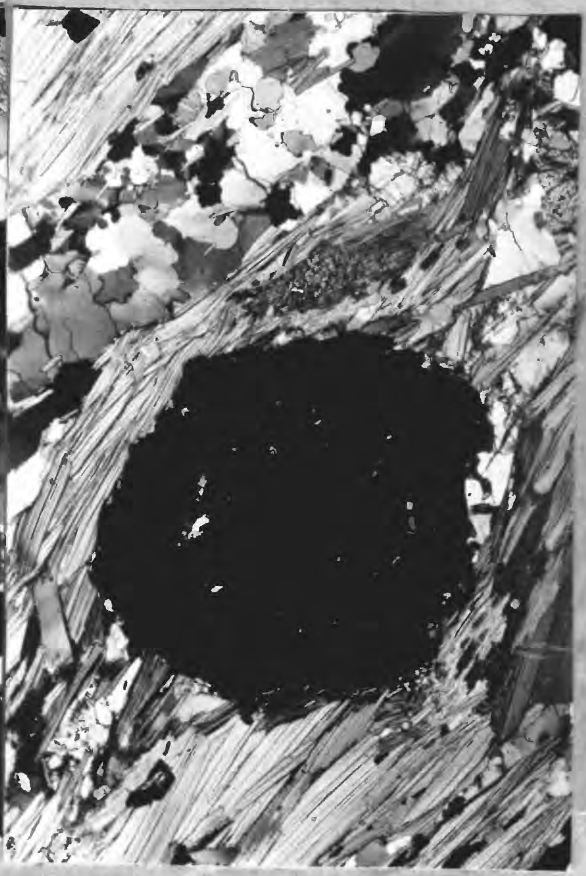
B. Oligoclase-biotite-quartz schist (X 16, X nicols). This mica schist has an undistorted fabric. The black grains scattered throughout the sample are magnetite-ilmenite. The oligoclase is albite-twinned. The biotite grains are about 2 millimeters long. Locality: near Deep Gap, Avery Co.

Mineral relationships.—The plagioclase of the mica rocks is oligoclase-andesine (An_{20}-An_{32}). The average plagioclase is oligoclase, An_{25} in the gneiss and An_{27} in the schist. Faint zoning is shown in crystals from scattered localities when the rim of the grain has a slightly smaller extinction angle than the center of the grain. This indicates normal zoning, i.e. the more sodic portion of the crystal toward the rim. No samples contained clearly defined zones of varying composition.

Twinning in the plagioclase is generally discernible in some grains in each thin section, though much of the oligoclase is untwinned. Simple albite twinning is the most common twin form (pl. 2 B), though some combined carlsbad-albite twinning was noted. In rocks with deformed fabrics, twins also may be distorted and at the same time untwinned oligoclase may exhibit undulose extinction.

Porphyroblastic plagioclase crystals are rarer in the gneiss than in the schist. Plate 6 A illustrates a 5-millimeter twinned oligoclase porphyroblast with inclusions of quartz, mica, and subhedral to euhedral garnets. Deformation after development of the porphyroblasts fractured them with the result that fine-grained mica, quartz, and feldspar fills the interstices of the larger remaining fragments. This crushing of the porphyroblasts produces a flaser structure (pl. 4 A).

The plagioclase may be partly sericitized, but this generally amounts to less than 5 percent of the total plagioclase volume. Other minerals associated with feldspar are apatite, generally as rounded grains, epidote as anhedral to subhedral crystals, and anhedral quartz grains. Tiny grains of zircon were found widely scattered in the oligoclase of the mica rocks.

A B

Plate 6

A. Oligoclase-muscovite-quartz-biotite-garnet schist (X 16, X nicols). A 5-millimeter (long dimension) albite-twinned oligoclase porphyroblast contains subhedral to euhedral garnet poikiloblasts and other small inclusions of mica and quartz. Undulose extinction is common in these porphyroblasts. Muscovite wraps around the large oligoclase crystals. Locality: Charlies Ridge mine, Avery Co.

B. Muscovite-oligoclase-biotite-quartz-garnet schist (X 16, X nicols). Muscovite is distorted around a 4-millimeter porphyroblast (dark rounded grain in center of picture). The dark blade with 2 cleavages and high relief in the muscovite, just above the garnet, is kyanite. The muscovite corrodes the kyanite and possibly some muscovite may have developed from kyanite. The quartz in the upper left has undulose extinction and contains small slivery inclusions of muscovite. Locality: near Boonford, Mitchell Co.

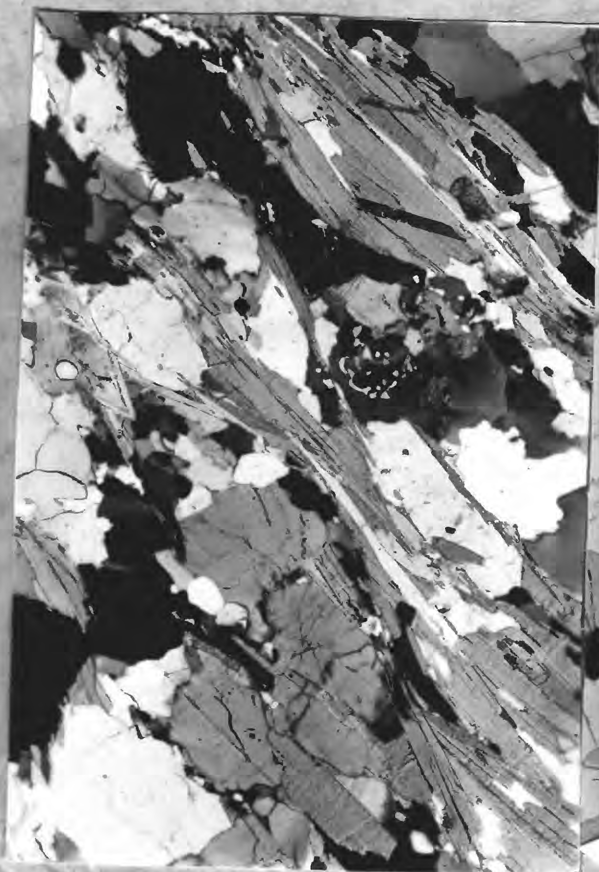
Potash feldspars are rare in the rocks of the Plumtree area. Orthoclase, as a chief constituent, was found only in minor varieties of the mica rocks where it occurs well scattered throughout the rock in a manner similar to plagioclase and quartz.

The quartz commonly has undulose extinction. In rocks with distorted foliation, quartz streaks are granulated or sutured and commonly contain included mica slivers (pl. 6 B). Symplectite, a vermiform intergrowth of quartz and feldspar, was noted in several samples (pl. 7 A).

The biotite commonly contains zircon inclusions which may be as large as 0.5 millimeter across the largest dimensions and are generally surrounded by pleochroic haloes. Magnetite-ilmenite lies along the cleavage planes or in clusters interstitial to grains of biotite (or muscovite). Other minerals associated with or included in biotite are green chlorite, epidote, allanite, sphene, quartz, pyrite, and pyrrhotite.

The usual position of biotite and muscovite within mica gneiss and schist layers has been described and illustrated in the discussion on the texture of the mica rocks. The biotite is generally well distributed throughout layers of mica gneiss and tends to be concentrated in streaks in the schistose rocks. The biotite foliae may or may not wrap around garnet or other porphyroblasts, depending on the relative ages of deformation to porphyroblast and biotite development. Where deformation has occurred after the formation of the biotite, undulose extinction is common.

The biotite of the mica gneisses and schists is of three types, brown-green, dark brown, and red-brown in the respective proportionate abundance of 4:2:1. There is no obvious pattern to the areal distribution of the three types. The biotite of a given rock layer is of only one type, although neighboring layers may contain the same or another type.



A B

Plate 7

A. Oligoclase-biotite-quartz gneiss (X 30, X nicols) with vermiform intergrowth of quartz in orthoclase (near the center of the photograph). The average grain size of this rock is about 0.5 millimeter. Other oligoclase and quartz grains are indistinguishable in the photograph because of the absence of twinning in the feldspar. Locality: Mill Shoal Ridge, Avery Co.

B. Oligoclase-biotite-quartz-garnet gneiss (X 30, normal light) with helizitic inclusions of kyanite with the cleavage oriented at right angles to the cleavage traces of the host muscovite. This is suggestive that the kyanite predated the muscovite. Fractured subhedral garnets (high relief) encroached on the mica and kyanite without distorting the fabric. Muscovite (light gray) and biotite (dark gray) are intergrown (upper third of photograph). The opaque (black) grains are magnetite-ilmenite. Locality: Doublehead Mountain, Avery Co.

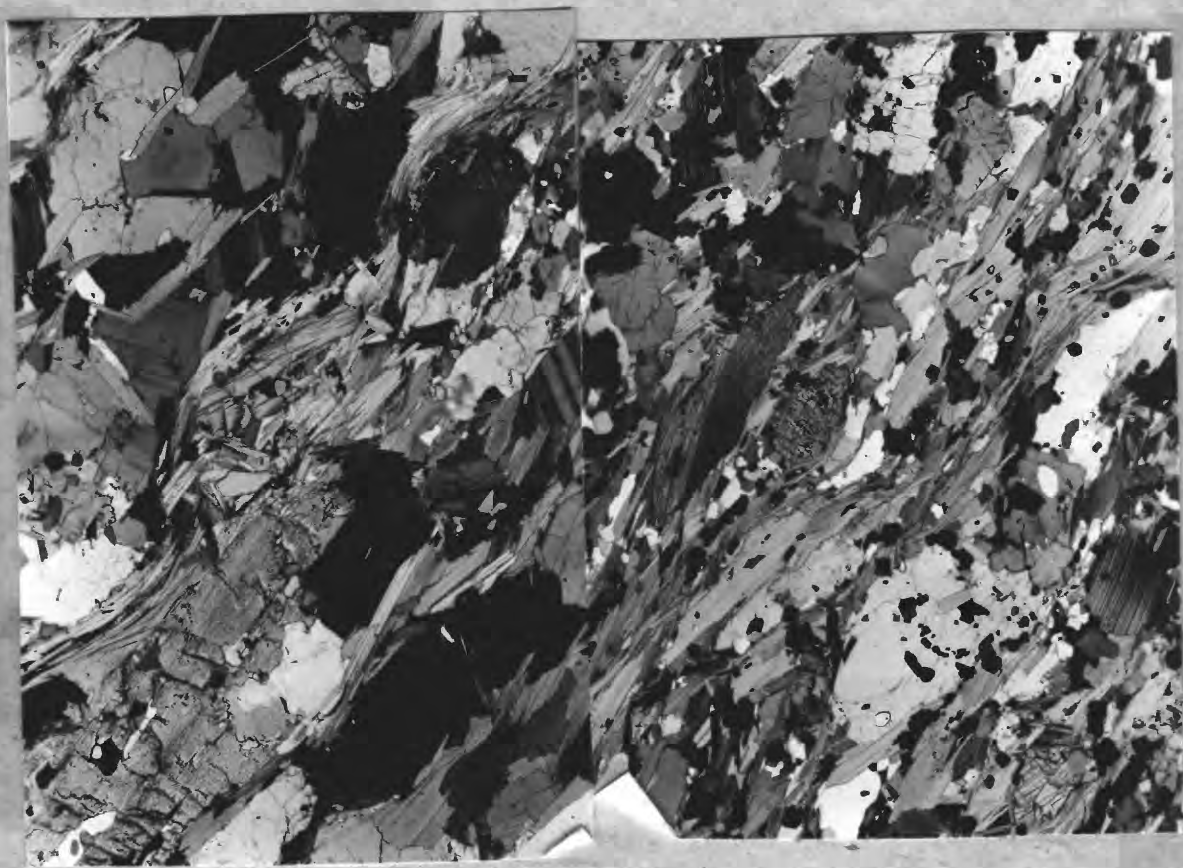
The brown-green type (X = light yellow, Y = light brown, Z = brown-green) has an average median refractive index of 1.634 in 23 samples. The red brown type (X = light brown, Y = light red-brown, Z = red-brown) has an average median index of 1.636 in 11 samples. The least common dark brown biotite (X = light yellow-brown, Y = yellow-brown, Z = dark brown) also has an average median index of 1.636 in 7 samples. The birefringence, approximately .05, is similar in the three types. The 2V is uniformly small.

According to Winchell (1951, p. 374) the indices of refraction indicate iron-magnesium biotites. The dark brown and red-brown varieties probably represent compositions richer in iron with some titanium (Wyckoff, 1952, p. 36; Rankama and Sahama, 1950, p. 561).

The muscovite (β 1.604, 2V about 45), according to Winchell (1951, p. 368), is a high alumina variety. It is generally intergrown with biotite, if the two micas occur together (pl. 7 B). The relationship of muscovite to other minerals is generally similar to that already described for biotite.

Helizitic kyanite in muscovite was found in several mica rocks (pl. 7 B) where the relationship of these two minerals suggests that muscovite has developed from the kyanite. This same relationship of early kyanite and later muscovite can be seen on plate 6 B. Kyanite blades, some twinned (pl. 8 B), are commonly encroached upon by muscovite, plagioclase, and quartz (pl. 8 A) and cracks may be filled by sericite.

Kyanite porphyroblasts are more common in the mica schists than in the mica gneisses. The longest dimension of the white, green, or blue kyanite rarely exceeds 1 centimeter and commonly averages 5 millimeters. The weathering of kyanitic rocks generally results in residual concentrations of these small blades in the soil.



A B

Plate 8

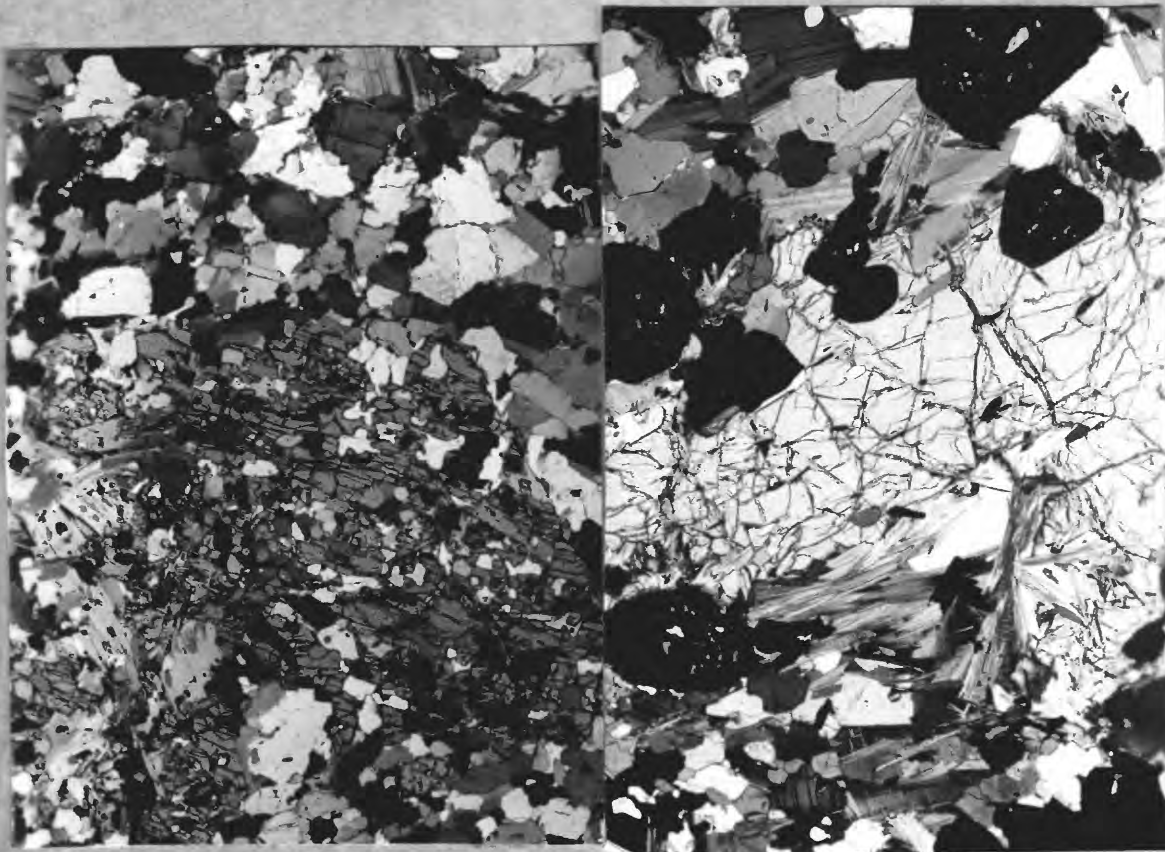
A. Oligoclase-biotite-quartz schist (X 16, X nicols) illustrating a 4-millimeter long kyanite porphyroblast corroded by quartz and oligoclase. The bent biotite grains suggest some post-recrystallization deformation of the rock. Locality: Dellinger Hollow, Mitchell Co.

B. Oligoclase-muscovite-quartz-biotite-garnet schist (X 16, X nicols) with twinned kyanite (high relief grain with good cleavage parallel to long dimension in left center of photograph). Note the quartz and oligoclase streaks separated by mica. The black grains are tiny 0.1 millimeter garnets and magnetite-ilmenite grains. Locality: Doublehead Mountain, Avery Co.

Staurolite with straw yellow pleochroism also forms small (1 to 5 millimeters) porphyroblasts in the mica rocks. Staurolite, however, is less abundant than kyanite. Sieve texture is common when the staurolite is filled with poikiloblasts of quartz, plagioclase, and magnetite-ilmenite (pl. 9 A). More homogeneous crystals may be encroached upon by later garnet, biotite, and chlorite (pl. 9 B). The fractures of the staurolite are filled with light green chlorite. Fibroblastic mica-chlorite schists contain staurolite crystals greatly corroded by chlorite (pl. 10 A).

Subhedral to euhedral crystals of light pink to red garnet are generally 0.1 to 2 millimeters in diameter, though porphyroblasts as large as 1 centimeter were found in some schists. Garnet is more abundant in the mica schist than in the mica gneiss. The garnets in the gneiss are generally 1 millimeter or less in diameter and those of the schists are larger and contain more inclusions. The inclusions are quartz, epidote, chlorite, and magnetite-ilmenite which may be oriented at random (pl. 10 B) or arranged in the circular pattern (pl. 6 B). Chlorite rims and fracture fillings in some garnets (pl. 10 B) are a common indication of retrograde metamorphism.

The foliation is variously distorted or not distorted around the garnets. Plates 6 B and 10 B illustrate the distorted foliation wrapped around the garnets. Fractured garnets with distorted foliation predate the deformation. Deformed foliation around unfractured garnets may have been caused by garnet growth or movement during growth. Plate 9 B shows a rock with late euhedral garnets which encroached upon the neighboring minerals without causing deformation.

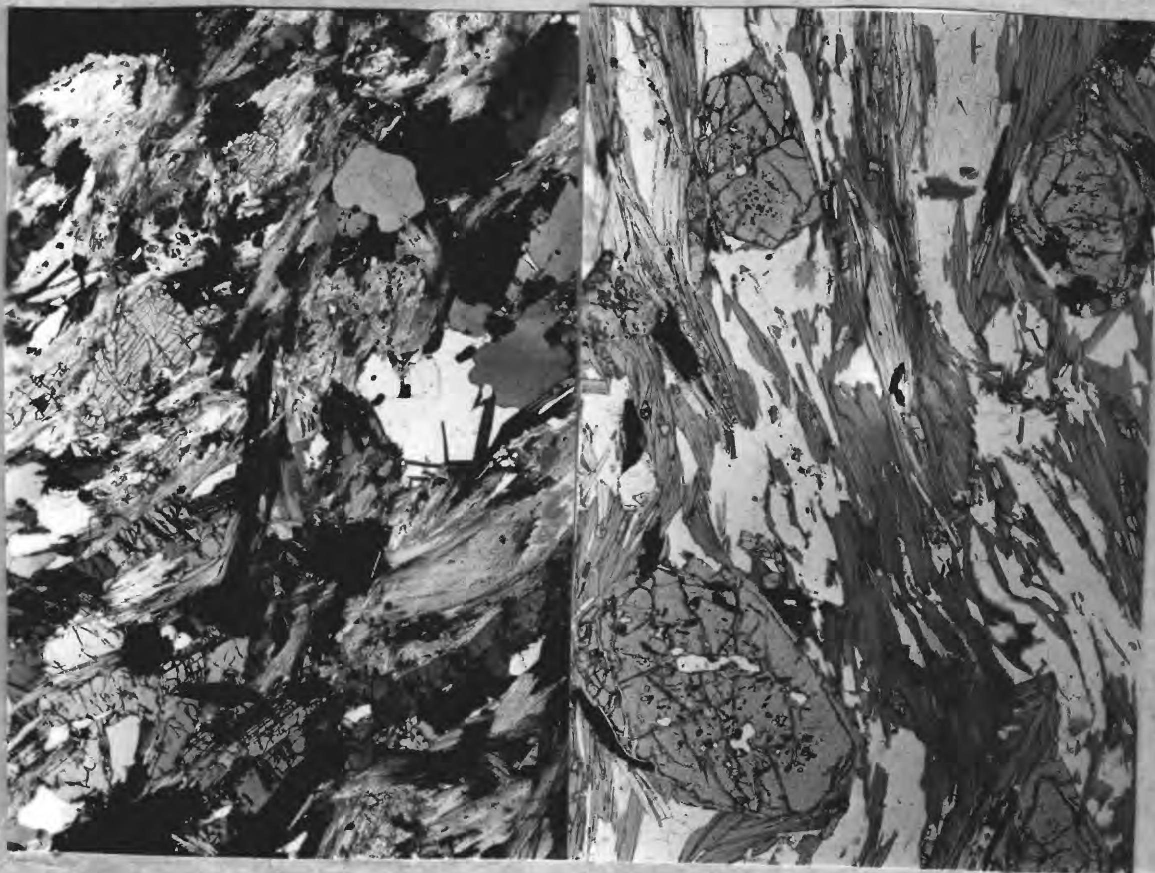


A B

Plate 9

A. Oligoclase-quartz-biotite-staurolite gneiss (X 16, X nicols) illustrating a 5-millimeter long porphyroblast of staurolite (high relief material in center of photograph). The "holes" of the staurolite sieve are occupied by quartz with some oligoclase. Locality: Long Level Mountain, Avery Co.

B. Oligoclase-garnet-quartz gneiss (X 16, X nicols) with a 6-millimeter long staurolite porphyroblast corroded by chlorite and encroached upon by later developed euhedral garnets (black grains 1 to 2 millimeters across). Chlorite also fills fractures in the staurolite. Locality: south slope of Long Level Mountain, Avery Co.



A B

Plate 10

A. Quartz-muscovite-chlorite-oligoclase schist (X 16, X nicols). Corroded staurolite (high relief, left center of photograph), oligoclase (lower left) in a fibroblastic mass of chlorite, muscovite, and quartz. Locality: Little Henson Creek valley, Avery Co.

B. Biotite-muscovite-quartz-oligoclase-garnet schist (X 16, normal light). This photograph exhibits mineral and textural relationships common in mica schist. The foliation is accentuated by abundant biotite with intergrown muscovite, distorted around subhedral garnets (high relief) filled with inclusions. Garnet is surrounded by thin (0.1 millimeter) rims of green chlorite. Prismatic epidote (high relief) is associated with the mica. Locality: outcrop at the south end of the Toe River bridge south of Ingalls, Avery Co.

The garnet is isotropic (N 1.805) with a specific gravity of nearly 4.2. The properties indicate that the composition is dominantly almandite-pyrope (Winchell 1951, p. 487) which is consistent with the findings of Wright (1937, p. 42).

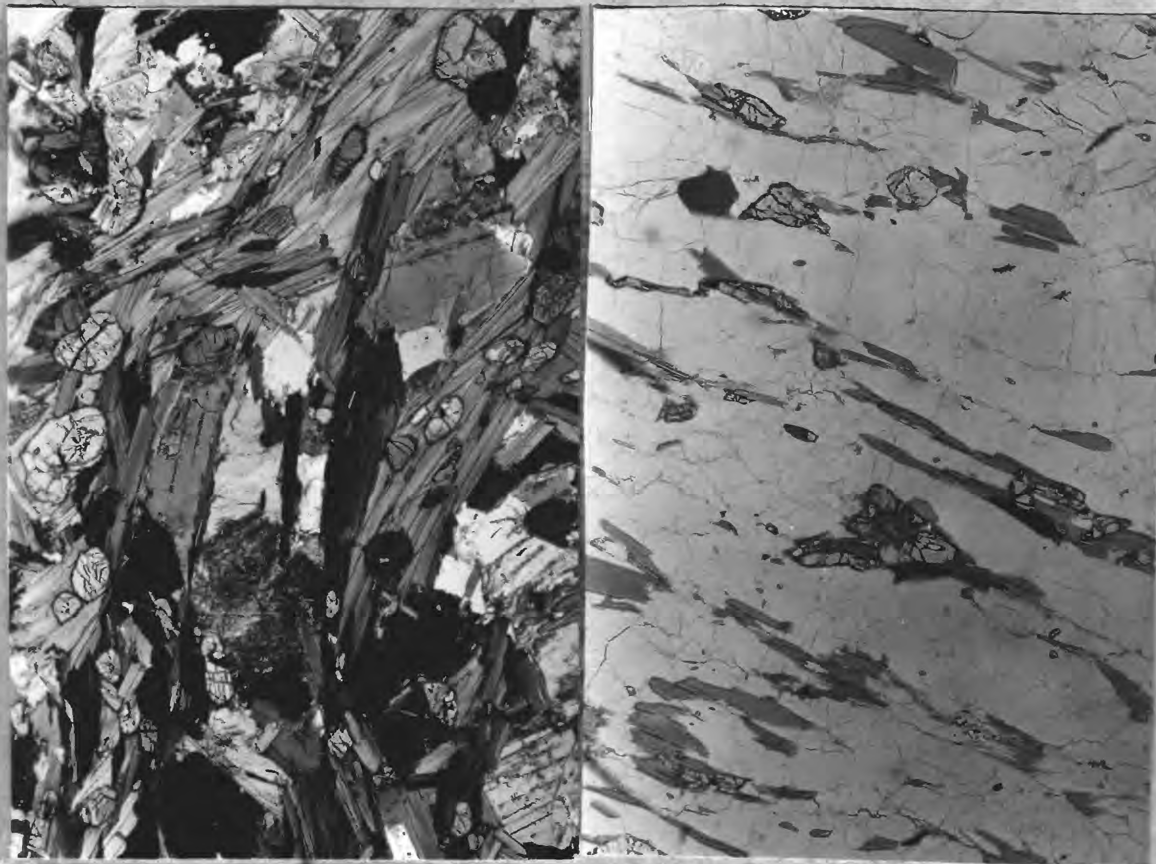
Epidote, a major constituent of some mica rocks, is commonly an accessory mineral. The epidote, colorless in thin section, may be associated with any of the major rock constituents; its occurrence and distribution in the mica rocks is completely unrestricted. It commonly forms clusters of fine grains or subhedral to euhedral crystals which are seldom larger than 0.5 millimeter in the longest dimension (pl. 11 A).

Brown allanite is a widespread accessory mineral which is most closely allied with epidote. The latter may form a colorless rim around a core of allanite; the contact between the rim and core is sharp (pl. 11 B).

Sphene, or the less common rutile, is generally associated with the biotite. Traces of pyrite and pyrrhotite are scattered throughout many mica rocks. Thin coatings of secondary oxides are associated with the magnetite-ilmenite and iron sulfides, especially in weathered rocks.

Traces of minor amounts of carbonate occupy a position interstitial to other minerals in a few of the samples studied. Small amounts of blue-green hornblende were found in mica rocks which lie close to hornblende-rich layers.

The presence of black organic matter in one sample (table 2, sample 14) was verified by chemical analysis (table 6, sample 4). It is probable that there are traces of organic matter in other samples.



A B

Plate 11

A. Biotite-oligoclase-epidote schist (X 16, X nicols). Rounded epidote grains (high relief) 0.5 to 1 millimeter are scattered throughout this rock, although the closest associate is biotite. The biotite crosscut by epidote and the undisturbed biotite enclosing it suggests that the epidote formed late. Locality: Slippery Elm mine, Avery Co.

B. Oligoclase-quartz-biotie-gneiss (X 30, normal light). The V-shaped grain (0.6 millimeter long dimension) in the center of the photograph is a combination of a colorless rim of epidote surrounding a core (0.2 millimeter long dimension) of brown allanite. These epidote-allanite grains are common in the mica rocks. Locality: Doublehead Mountain, Avery Co.

Hornblende rocks of the Roan-type

The undifferentiated hornblende rock unit (pl. 1) includes all those rocks with megascopically visible hornblende and those with actinolite, chlorite, epidote, zoisite, and diopside which are most closely associated with the hornblende-rich rocks. These rocks are interlayered and transitional to the mica rocks.

The rocks of this mappable unit range from gray-green to dark greenish black depending on the proportions of light to dark minerals. Foliation is generally well developed from the alignment of hornblende or other needle-shaped or platy minerals. The structures are schistose to gneissic and the textures are granoblastic to nematoblastic, though some hornblende rocks with biotite and chlorite are lepidoblastic or fibroblastic. The grain size ranges between 0.1 and 5 millimeters.

Most of the hornblende rocks are dense and have a tendency to break off in slabs. Soils developed from these rocks are generally dark red to reddish brown and are the most plastic soils in the area. There is a general lack of hydromica flakes and quartz grains in the soil developed from the most common and widespread of the hornblende rocks; it is, therefore, easily distinguished from the soil derived from the mica rocks.

The major mineral constituents of the rocks in this unit include hornblende, actinolite, oligoclase, andesine, quartz, epidote, zoisite, garnet, diopside, chlorite, and biotite. The accessory minerals include sphene, rutile, apatite, zircon, allanite, sericite, chlorite, calcite, orthoclase, magnetite-ilmenite, pyrite, and pyrrhotite.

The following mineralogical varieties were found in the hornblende unit:

H schist	A-H-Q-B gneiss
H-Q schist	A-Q-H gneiss
H-Q-Epi schist	A-Q-B-H gneiss
H-A gneiss	O-H-G-Di gneiss
H-O gneiss	O-Di-H gneiss
H-A-Di gneiss	Epi-H schist
H-A-Z gneiss	Epidotite
H-A-Z-Q gneiss	Act schist
H-Q-A gneiss	Z-Act-A gneiss
H-O-B gneiss	Q-Z-H gneiss
A-H-Q gneiss	Chl-A-H gneiss
H-A-Q-Epi gneiss	Act-Z schist

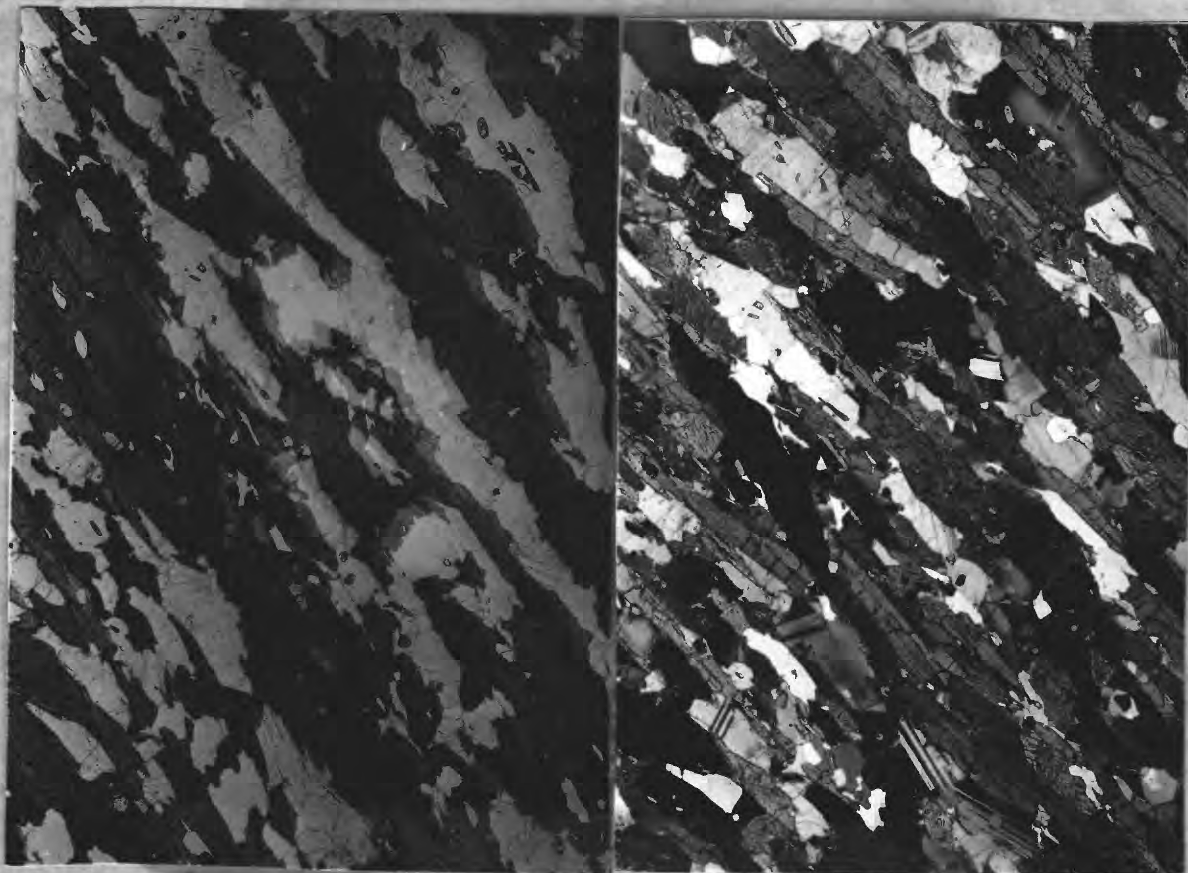
(H-hornblende, Q-quartz, Epi-epidote, A-andesine, O-oligoclase, Di-diopside, Z-zoisite, B-biotite, G-garnet, Act-actinolite, Chl-chlorite.)

Typical modes of these rocks are shown in table 4; chemical analyses are listed in table 7.

Although the relative abundance of the various types in the hornblende unit cannot be closely estimated, the hornblende rocks (50 percent or more hornblende) predominate and may make up about 80 percent of this unit. The remaining 20 percent is divided between the andesine or oligoclase-rich rocks (15 percent) and the other varieties (5 percent). Quartz and/or biotite, each amounting to 10 percent or more, occur in about 25 percent of the rocks mapped in the hornblende unit.

Petrography of the hornblende rocks

Structure and texture.--The structure of the rocks ranges from gneissic to schistose. Plates 12 A and 13A illustrate the gross difference between a common type of hornblende gneiss and a schist. The schist has a finer grain size, a smaller mineral assemblage and a more even distribution of the minerals within the layer than the gneiss.

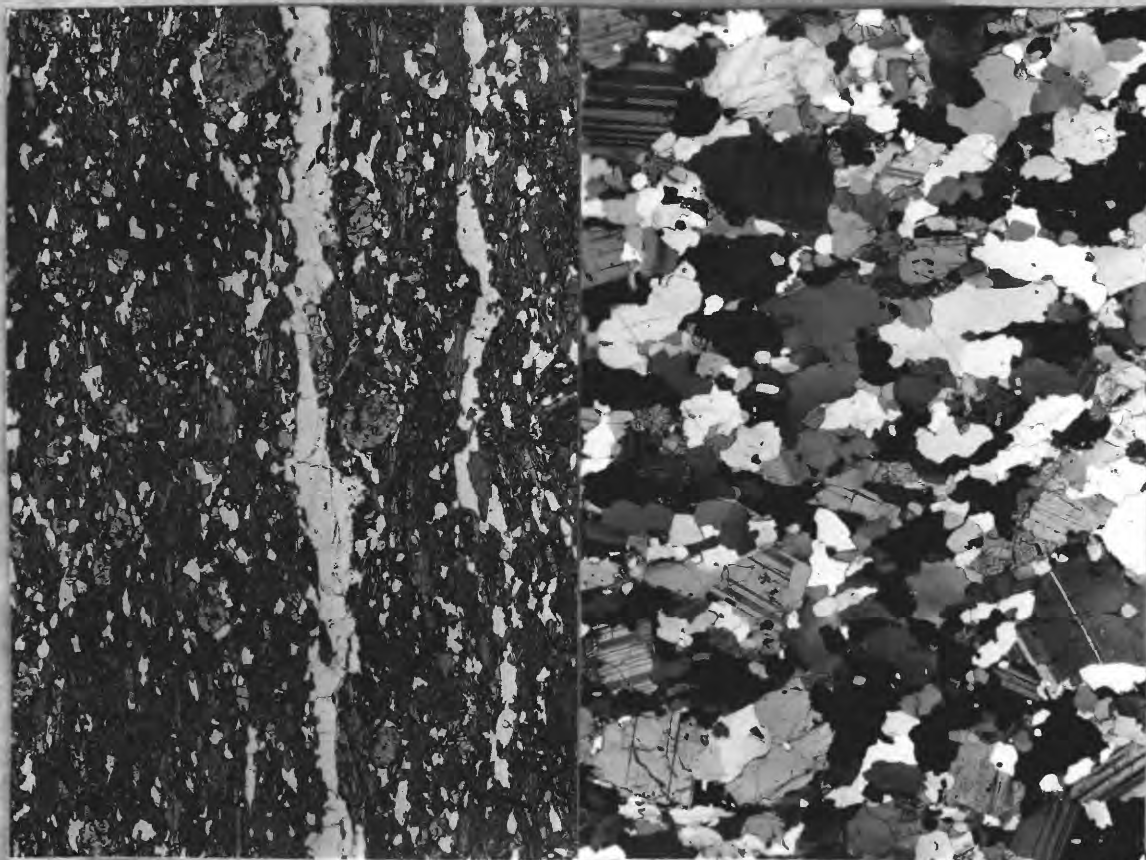


A B

Plate 12

A. Hornblende-andesine gneiss (X 16, normal light) illustrating the typical nematoblastic texture of many hornblende-rich rocks. The small dark grains are rutile, the white streaks are andesine with some quartz, the remaining grains are hornblende with included epidote (elongate grains with relief like hornblende, but lighter gray color). Locality: Cane Creek Mountain, Mitchell Co.

B. Hornblende-andesine gneiss (X 16)--the same as A, but with X nicols showing albite twinning and suggestion of zonation (upper right) in the andesine. The white streak left of center is quartz.



A B

Plate 13

A. Hornblende-quartz schist (X 16, normal light) with a thin streak of quartz and rounded garnets, the largest of which in the top center is nearly 1 millimeter across. All of the white grains are quartz, the dark grains are hornblende with some magnetite-ilmenite, sphene, and epidote. There is a marked textural difference between this schist and the hornblende-andesine gneiss in Plate 12. The sample is from Charlies Ridge, in the Henson Creek area, Avery Co.

B. Andesine-quartz-hornblende gneiss (X 16, X nicols) illustrating the granoblastic texture of the hornblende rocks. Much of the andesine is albite-twinned and the quartz exhibits the common undulose extinction. Locality: 100 feet north of altitude 2,924 feet along U. S. route 19E north of Plumtree, Avery Co.

Table 4

Modes of unaltered and altered hornblende rocks

	1	2	3	4	5	6	7	8	9	10
Hornblende	80	65	70	52	60	50	60	55	20	20
Plagioclase	5	5	20	25	23	15	10	25	55	55
An of plagioclase	35	32	35	32	35	25	32	25	32	33
Quartz	10	20	5		tr	10	15	5	15	25
Epidote	5	10					2	2	5	tr
Zoisite					15	15				
Garnet							3			
Sphene				3	2	3	1	3		tr
Rutile			3							
Magnetite) Ilmenite)	tr						1	1		
Chlorite	tr						tr			
Sericite				tr		5	tr	tr	tr	
Diopside				20						
Biotite						2	7	10	3	
Apatite							tr	tr	tr	tr
Zircon							tr	tr	tr	tr

1. H-Q schist from Cane Creek mountain, Mitchell Co.
2. H-Q-Epi schist from near Richs Gap, Avery Co.
3. H-A gneiss from Cane Creek Mountain, Mitchell Co.
4. H-A-Di gneiss from along U. S. route 19E at the base of Mill Shoal Ridge, north of Plumtree, Avery Co.
5. H-A-Z gneiss from Oaks Knob, Avery Co.
6. H-A -Z-Q gneiss from Doublehead Mountain, Avery Co.
7. H-Q-A gneiss from near the Landers mine in Henson Creek valley, Avery Co.
8. H-O -B gneiss from near Dayton Bend along the Toe River, Yancey Co.
9. A -H-Q gneiss from Mill Shoal Ridge, Avery Co.
10. A -Q-H gneiss along U. S. route 19E along the base of Mill Shoal Ridge, Avery Co.

(H-hornblende, Q-quartz, Epi-epidote, A-andesine, O-oligoclase, Di-diopside, Z-zoisite, B-biotite.)

(Table 4 continued on next page)

Table 4 (continued)

	11	12	13	14	15	16	17	18	19	20
Hornblende	10	20	15	40				10	23	
Plagioclase	52	41	65				15		35	23
An of plagioclase	33	26	28				30		30	28
Quartz	20	5		5	tr			50	5	40
Epidote	tr			50	95					tr
Zoisite						30	65	40		
Garnet	2	15		2						5
Sphene	tr	2	tr		tr		3		2	tr
Rutile										
Magnetite) Ilmenite)	tr				2				tr	
Chlorite				tr	2	tr			30	
Sericite										tr
Diopside		15	20							
Biotite	15								5	25
Apatite	tr									tr
Zircon	tr		tr							tr
Pyrite		2								2
Calcite				tr						
Actinolite						60	17			
Allanite										
Orthoclase										5

11. A -Q-B-H gneiss from the ridge west of Copperas Bald near Frank, Avery Co.
12. O -H-G-Di gneiss from along U. S. route 19E near Frank, Avery Co.
13. O -H-Di gneiss from Teagues Ridge, Avery Co.
14. Epi-H schist from Teagues Ridge, Avery Co.
15. Epidotite from Charlies Ridge.
16. Act-Z schist from a southeast spur of Hawk Mountain, Mitchell Co.
17. Z-Act-A gneiss from along U. S. route 19E at the base of Mill Shoal Ridge, north of Plumtree, Avery Co.
18. Q-Z-H gneiss from the south slope of Pine Mountain near Spruce Pine, Mitchell Co.
19. Chl-A -H gneiss, a hydrothermally altered hornblende gneiss from the Little Henson Creek Valley, Avery Co.
20. Q-B-O schist derived from an H-Ad gneiss by contact action of a pegmatite in the upper Henson Creek valley, Mitchell Co.

(H-hornblende, Q-quartz, Epi-epidote, A-andesine, O-oligoclase, Di-diopside, Z-zoisite, B-biotite, Act-actinolite, Chl-chlorite, tr-traces.)

These same plates show the common nematoblastic texture (pl. 12 A) and granoblastic texture (pl. 13 A). As the amount of platy or prismatic minerals decreases, the granoblastic textures predominate, as in the andesine-quartz-hornblende gneiss (pl. 13 B).

Porphyroblasts of hornblende (pl. 14), garnet (pl. 13 A), and flaser structures occur in the rocks of this group. Thin (1 millimeter or less) discontinuous streaks of feldspar and/or quartz parallel to the foliation also are common (pl. 13 A). Veinlets of epidote (pl. 14 B) up to a quarter of an inch thick may crosscut layers of hornblende and mica rocks. Lepidoblastic or fibroblastic textures are generally restricted to the rocks of this unit which contain biotite and chlorite in amounts over 10 percent. The chlorite rocks are most common in the sheared zones where hydrothermal alteration has occurred.

<u>Mineral relationships</u>.—The green hornblende occurs in elongate, subhedral crystals which impart a foliation to the rocks of this group. Inclusions of quartz, feldspar, sphene, rutile, epidote, zoisite, and allanite are common. Chlorite and biotite may be formed from the hornblende in the altered rocks of this unit.

The optical properties of the hornblende (α 1.652-1.654, β 1.166-1.672, γ 1.674-1.678; large 2V(-); $Z \wedge c$ approximately 20; X = greenish yellow; Y = olive-green; Z = bluish green) indicate a probable uniformity of composition.

A B

Plate 14

A. Andesine-quartz-biotite-hornblende gneiss (X 16, normal light) with hornblende porphyroblasts 4 millimeters long on the left. The white background is quartz and andesine. Among the accessory minerals are euhedral garnets (center and lower right), apatite (gray rounded grain with medium relief in upper right), and zircon with a dark pleochroic haloes in biotite (in the center of the photograph). Rocks with this texture and composition are characteristic of the layers in the transition between the common hornblende and mica rock types. The sample is from near altitude 3,666 feet on the ridge west of Copperas Bald near Frank, Avery Co.

B. Hornblende-oligoclase gneiss (X 16, normal light) cut by a 0.5 millimeter-thick veinlet of light green epidote. The gray grains with two cleavages are hornblende and the white grains are plagioclase and quartz. The epidote is a fracture filling and the hornblende is concentrated near the vein to the exclusion of the plagioclase and quartz. Locality: 500 feet north of altitude 2,924 feet along U. S. route 19E, north of Plumtree, Avery Co.

The approximate formula (table 5) of this common hornblende has been calculated from the analysis of a monomineralic hornblende schist cropping out along North Carolina highway number 80 about 2 miles east of Kona. The calculation shows that there is more aluminum than is likely to proxy for silicon and that traces of alkali are substituting for some lime.

The plagioclase (An_{25-38}) in the rocks of this unit may be widely distributed, as in the plagioclase-rich types (pl. 13 B), or segregated in streaks or clots, as in the hornblende-rich types (pl. 12 B). Poikiloblasts of plagioclase are common in the hornblende. Small amounts of sericite have replaced some of the plagioclase.

Although much of the plagioclase is untwinned, albite and pericline twins were found; the former type being most common (pls. 12 B and 13 B).

Variation of the extinction between the center and edge of some plagioclase grains suggests zoning. In the upper corner of plate 12 B the large andesine crystal has a rim which is nearly extinguished when the core is illuminated. None of the samples display clear cut zoning. The plagioclase of the hornblende and mica rocks is similar with respect to twinning and zoning.

Quartz, at least in small amounts, is common in the hornblende rocks. It generally occurs as disseminated grains or streaks (pl. 13 A) with undulose extinction and a granoblastic to sutured texture. The streaks are generally discontinuous and their thickness is 0.5 to 5 millimeters.

Table 5

Formula of the hornblende near Kona

	Weight 1/ (percent)	Cations to 24 OH and O	Cations available	Actual grouping
SiO_2	46.63	6.65	8.92	8.00
Al_2O_3	13.54	2.275		
TiO_2	.27	.03		
Fe_2O_3	2.32	.24		
MgO	14.33	3.05	4.31	5.23 2/
FeO	8.13	.97		
MnO	.19	.02		
Na_2O	.14	.03		
K_2O	1.17	.20	1.94	1.94
CaO	11.24	1.71		
H_2O	2.08	1.98	1.98	1.98

The formula of the hornblende is:

$(Ca,Na,K)_{1.9}Mg_2(Mg,Fe^{++}, Mn^{++}, Fe^{+++}, Ti,Al)_3 (Si,Al)_2 Si_6O_{22}(OH)_2$

1/ R. H. Stokes, analyst U.S.G.S. Rock Analysis Laboratory, Denver, Colo.

2/ Includes .92 Al, the excess from the Al-Si group.

Biotite, in disseminated flakes, is most common in the hornblende rocks which are transitional to the mica rocks (table 4, samples 8 and 11). Optically, this biotite is similar to that of the mica rocks. The brown-green and red-brown varieities are most abundant. Muscovite and zircon if present are associated with the biotite.

Garnet is not as abundant in the hornblende rocks as it is in the mica rocks. Although some hornblende layers contain up to 15 percent red garnet (table 4, sample 12), it is usually an accessory mineral. The anhedral to euhedral grains range from 0.3 to 5 millimeters in diameter. The average index of refraction of 7 garnet samples is 1.790 (the range is 1.785 to 1.795) and the specific gravity is nearly 4. These properties indicate that almandite and pyrope are predominant as in the garnet of the mica rocks, but the lower specific gravity here suggests that some grossularite (calcium) may also be present. This composition is agreeable with the findings of Wright (1937, p. 47).

Bright green diopside as subhedral grains is associated with hornblende and andesine in several rock types. Diopsidic layers are intimately associated with hornblende-andesine gneiss along U. S. route 19E 2.5 miles north of Plumtree.

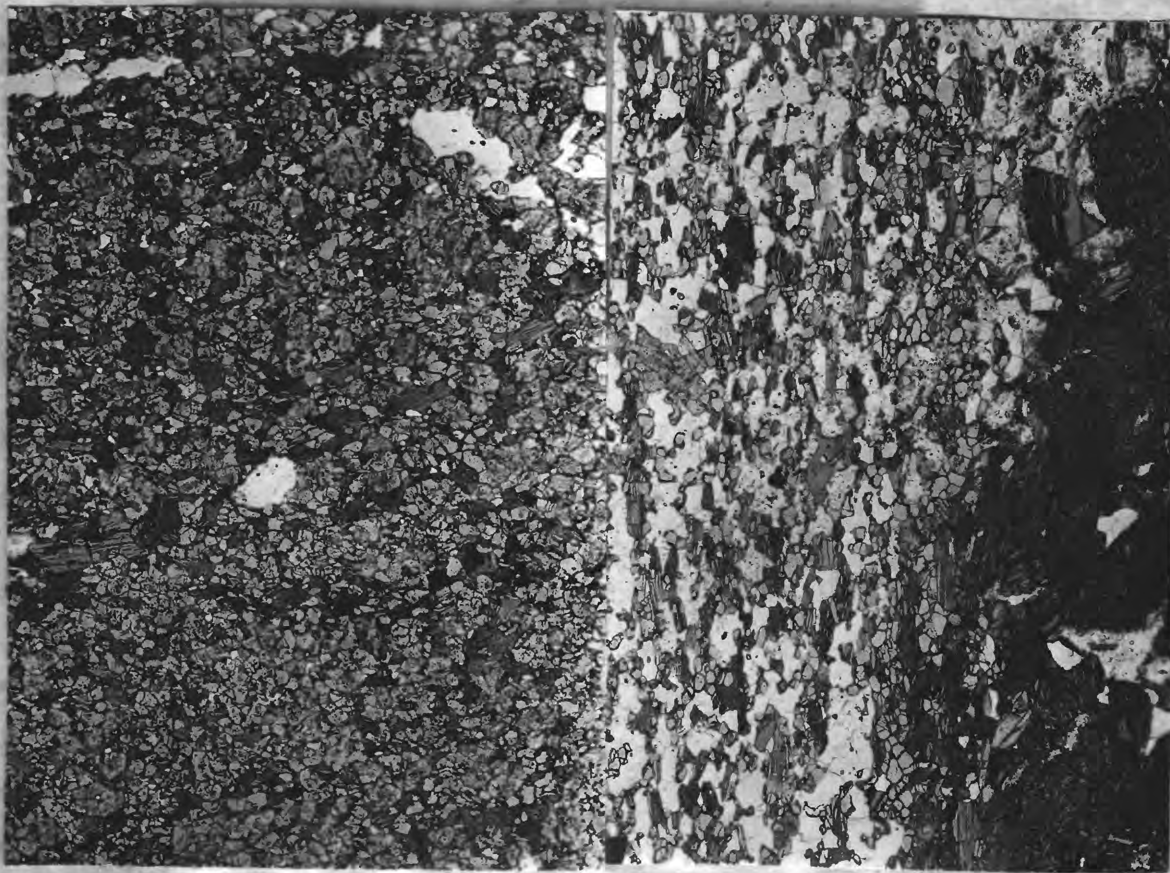
The occurrence of epidote is three-fold: (1) it is a common accessory mineral in many hornblende-rich rocks, (2) it may be a chief constituent of some layers, such as the epidote-hornblende schist or the epidotite, and (3) it fills veins which crosscut the foliation and layers of hornblende rocks.

As an accessory mineral, epidote generally is disseminated through the rocks as isolated subhedral grains or it is included in the hornblende. In some layers, the epidote has cores of brown allanite similar to those found in the mica rocks.

In the epidote-hornblende schists the sugary grained epidote forms a groundmass for scattered grains of uncorroded hornblende (pl. 15 A). Plate 15 B illustrates the contact between a quartz-epidote-hornblende schist and a hornblende-andesine gneiss. There is a sharp contact between the two layers where the grain size changes abruptly.

The epidotites, generally associated with the epidote-hornblende schists, are sugary grained rocks with streaks or scattered grains of quartz (pl. 16 A), scattered magnetite-ilmenite, and perhaps some green chlorite (table 4, sample 19). The epidote has yellow pleochroism and a large 2V. The indices of refraction are α 1.725, β 1.742, γ 1.750 in three samples. According to Larsen and Berman (1934, p. 232) these indices characterize an epidote with Al:Fe:9:2.

The crosscutting veins of finely granular epidote are 1 millimeter to 1 centimeter thick. The index of refraction of vein epidote from 2 samples is α 1.735, β 1.755, γ 1.765. The Al:Fe is 5:3 (Larsen and Berman, 1934, p. 232), indicating nearly three times the amount of iron as compared to 9:2 ratio in the epidote of the epidotite.

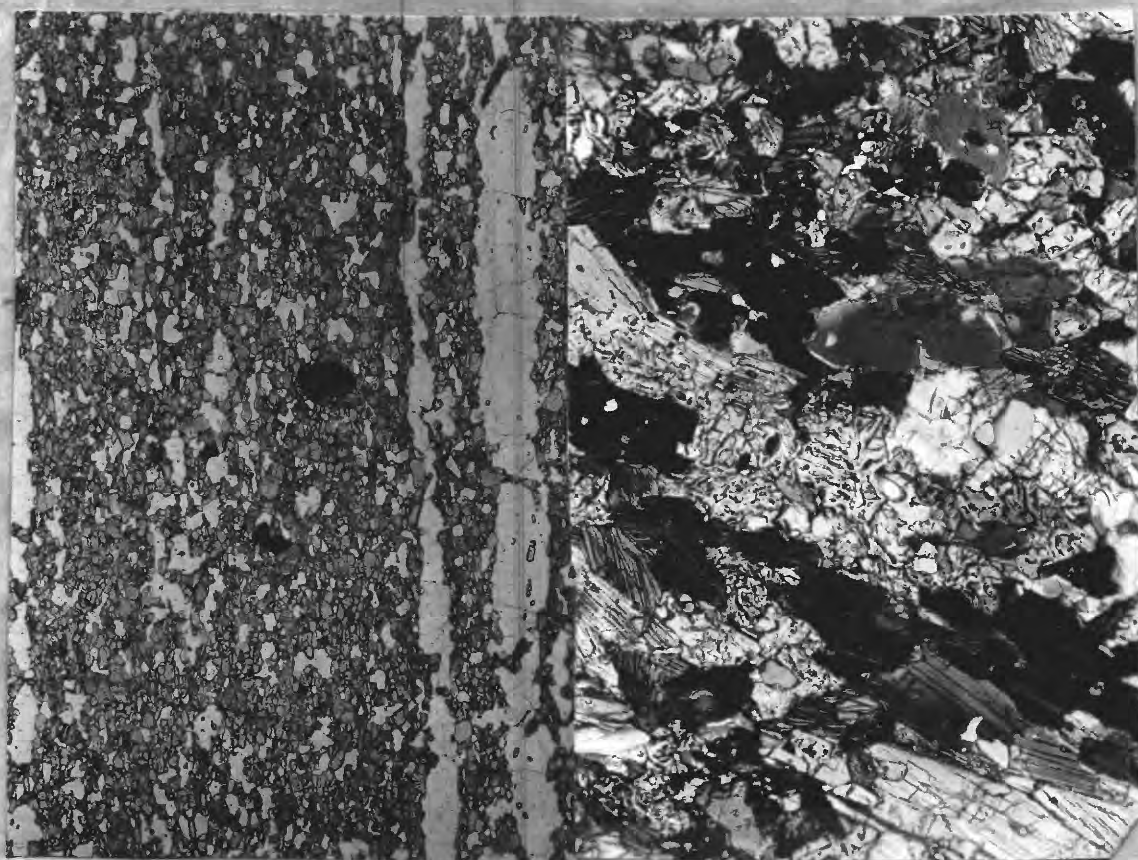


A B

Plate 15

A. Epidote-hornblende schist (X 16, normal light) with fine grained epidote (gray grains, some with one cleavage), hornblende (dark grains, some with 2 cleavages), and quartz (white grains). Locality: North end of Mill Shoal Ridge, Avery Co.

B. A contact between quartz-epidote hornblende schist (left) and a hornblende-andesine gneiss (right) showing the well defined change of composition and grain size. The hornblende grains on the right are about 1 millimeter across. Epidote (gray) has high relief, quartz is white, and hornblende is dark, displaying one or two good cleavage traces. White grains on the right are andesine. Locality: quarry along the east side of Crabtree Creek, 500 feet north of its intersection with U. S. route 19E, 4 miles west of Spruce Pine, Mitchell Co. (X 16, normal light.)



A B

Plate 16

A. Epidotite (X 16, normal light) with the typical association of sugary grained epidote with both disseminated grains and streaks of quartz. The black grains are accessory magnetite-ilmenite. Locality: quarry along the east side of Crabtree Creek 500 feet north of U. S. route 19E, 4 miles west of Spruce Pine, Mitchell Co.

B. Hornblende-andesine-zoisite-quartz gneiss (X 30, X nicols) exhibiting a kelyphitic texture of vermiform quartz in zoisite (gray grains in the center). Notice the lack of twinning in the andesine (light grains in the right center). The sample is from near Doublehead Gap, on Doublehead mountain, Avery Co.

Zoisite is intimately associated with the hornblende, quartz, and plagioclase. In this respect its position in the rock is similar to that of epidote. Kelyphitic intergrowths of zoisite and quartz are abundant (pl. 16 B). Zoisite in elongate, flattened streaks of flasered augen 2 millimeters thick and 2.5 centimeters long make up 15 percent of a hornblende rock (table 4, sample 5) on the south slopes of Oaks Knob. The zoisite masses are made up of aggregates of subhedral crystals averaging 25 centimeters across and flattened in the plane of the foliation.

Green actinolite occurs in various gneisses and schists with relationships to other minerals similar to those already described for hornblende. The refractive indices are α 1.628, β 1.648, γ 1.654.

The suite of accessory minerals in the rocks of this unit is varied. Sphene as subhedral to rounded grains is scattered through the rock as inclusions in hornblende or clusters interstitial to hornblende. Rutile may occupy a similar position, but rarely do rutile and sphene occur in the same rock. Widely distributed subhedral grains or clusters of magnetite-ilmenite are associated with hornblende and biotite. Small amounts of disseminated pyrite and pyrrhotite are common. Apatite as rounded grains occurs with hornblende and plagioclase in many rocks of this unit, although it is most common in the hornblende rocks which also have biotite. Apatite, zircon, and biotite in these rocks suggests compositions transitional between the rocks of the hornblende and mica units. Small patches of carbonate minerals were observed between the main minerals in a few samples. Traces of allanite commonly accompany epidote, zoisite, and hornblende. Minor amounts of light green chlorite may be associated with garnet and hornblende. Chlorite, calcite, sericite, and orthoclase are common in the contact or hydrothermally altered rocks of this group.

Quartzite

Although the white to reddish quartzites do not form a mappable unit, they are widely distributed in layers up to 2 feet thick in the metamorphic sequence. Micaceous and hornblendic rocks grade to quartzite as the amount of quartz increases to 75 percent or more of the rock. The quartzite layers do not constitute over 5 percent of the rocks in the Plumtree area, and are not continuous over sufficiently large areas to make good horizon markers.

The mode of a typical quartzite from the south slopes of Doublehead Mountain is listed in table 3, sample 15. The grains are generally under 1 millimeter and foliation is generally indistinct. The most common accessory minerals include muscovite, biotite, hornblende, zircon, rutile, and plagioclase.

On the slopes of Long Level Mountain 1,000 feet northeast of the junction of Little Henson Creek and Henson Creek roads float of white, fine-grained, quartzite contains porphyroblasts of green kyanite. The porphyroblasts, as large as 2 by 5 centimeters, make up 5 percent of the rock and give it a foliate structure.

Cranberry gneiss

Some layers typical of the Cranberry gneiss (Keith, 1903, 1907) are intercalated with the other metamorphic rocks along the northwest and east borders of the area which are close to the contact of the large body of Cranberry gneiss that surrounds the Spruce Pine district on three sides.

The white to gray gneisses are composed chiefly of microcline, sodic plagioclase, and quartz. In some layers biotite, muscovite, and (rarely) hornblende may be present in amounts over 10 percent. Generally the accessory minerals include some of the following: biotite, hornblende, muscovite, garnet, apatite, zircon, tourmaline, sphene, chlorite, and magnetite-ilmenite. The mode and calculated analysis of a common type of Cranberry gneiss are given on table 8.

The texture is cataclastic (pl. 17 A) with rounded and fractured porphyroblasts of microcline or plagioclase from 3 millimeters to 1 centimeter across the largest dimension. The fractured grains are usually healed by fine-grained feldspar quartz. The lamellae of twinned feldspar grains may be bent. Quartz and plagioclase commonly display undulose extinction.

Contact and hydrothermally altered rocks

The hornblende and mica rocks have been altered by hydrothermal solutions moving along minor shear zones, and by contact metamorphism caused by the introduction of alaskite and diabase.

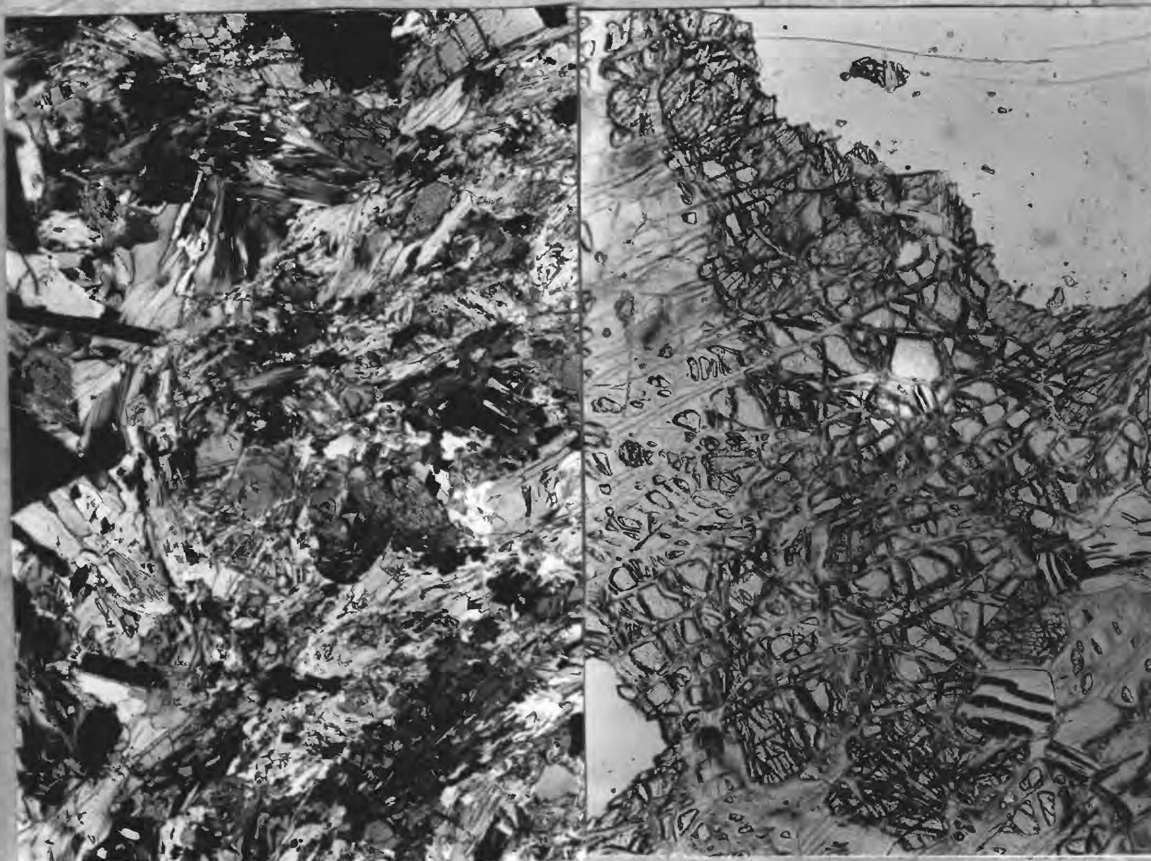
The effects of contact and hydrothermal metamorphism are most marked on the hornblende rocks. In either process, the hornblende is altered to biotite, usually of the red-brown type, and chlorite of the amesite type (β 1.604). Cataclastic textures are common especially in the rocks of the shear zones, but similar textures in contact altered rocks (pl. 17 B) attest to the pressure involved in pegmatite emplacement. Additions of quartz and sulfides, generally pyrite and pyrrhotite, occur in both types of alteration. The plumose textures of the platy minerals (pl. 18 A) and the numerous slickensided shear surfaces make sheared rocks distinctive in the field. The formation of potash feldspar is generally restricted to altered rocks adjacent to pegmatites. The modes of typical altered hornblende rocks are listed in table 3.

A B

Plate 17

A. Cranberry gneiss (X 16, X nicols) consisting mostly of perthitic microcline (large spotted crystal) and quartz illustrating the cataclastic texture. The large microcline grain is fractured and healed (on the right) by finer grained microcline. The groundmass at the top and bottom of the photograph is mostly granulated microcline and quartz. Locality: the ridge west of Beech Bottom, along the North Toe River, Avery Co.

B. Biotite-quartz-andesine-garnet-chlorite schist (X 16, X nicols) with a cataclastic fabric. A quartz vein cuts across the lower right next to thin layers of red-brown biotite and fine quartz. Andesine (An_{34}) with thin albite twinning is about 1 millimeter across. All of the hornblende has been altered to biotite. Accessory minerals include epidote, apatite, zircon, sphene, and pyrite. The sample is from the altered hornblende wall rock at an unnamed pegmatite mine near the head of Henson Creek, Mitchell Co.



A B

Plate 18

A. Andesine-chlorite-hornblende gneiss (X 16, X nicols) illustrating the lepidoblastic or fibroblastic texture common in the biotite- or chlorite-rich varieties of the altered hornblende rocks. The fibrous chlorite and biotite corrode and fill the interstices of the hornblende and plagioclase grains. The confused texture and the broken feldspar and hornblende grains indicate that this rock has been sheared. Locality: about altitude 3,600 feet along the Little Henson Creek road, Avery Co.

B. Serpentinized dunite (X 30, normal light) from the Frank body in Avery County. Outlines of a fracture system are preserved in the serpentine (upper left). Gray grains with high relief are the remnants of olivine. The dark streaks in the olivine (lower right) are fine-grained aggregates of chromite and magnetite.

Contact metamorphic effects on the mica rocks by alaskite are not generally as noticeable as they are on the hornblende rocks because of the greater chemical similarity between the alaskite and mica rocks than between the alaskite and hornblende rocks. The most common effect of pegmatite emplacement in mica rocks, especially the schists, is the local development of lit-par-lit injection gneiss where quartz and feldspar have been forcefully added to the wall rocks.

Hydrothermal alteration of the mica rocks in shear zones has resulted in the chloritization of biotite and minor additions of quartz and sulfides.

The contact actions of pegmatitic fluids on dunite produces phlogopite, anthophyllite, talc, and serpentine, in that order, from the pegmatite contact into the dunite body, indicating that silica, potash, alumina, and water have been added to the dunite. These alterations cause the pegmatite near the dunite to be poorer in quartz, potash feldspar, and muscovite than other parts of the pegmatite away from the contact.

Where diabase dikes cut pegmatites there are alteration zones 1 to 3 millimeters thick on each side of the contacts: in the pegmatite, the feldspar is altered to a dusty brown; in the dike the augite is replaced by a fine aggregate of biotite and chlorite. The only apparent effect of the diabase intrusion on the country rocks was the formation of scattered patches of zeolite on the interlayer faces of the host rocks.

Igneous rocks

Alaskite and pegmatitic alaskite

Hunter (1940) was the first to apply the term alaskite in the Spruce Pine district. The term was introduced by Spurr (1900) for a plutonic rock characterized by alkali feldspar and quartz with little or no dark component.

The chief minerals of the alaskite and associated pegmatite are, in the order of abundance, plagioclase, An_5-An_{30} according to Maurice (1940), perthitic microcline, quartz, and muscovite. Accessory minerals include biotite, sericite, garnet (especially near hornblende rock contacts), thulite, monazite, apatite, tourmaline, beryl, allanite, uraninite, uranophane, torbernite, samarskite, tantalite-columbite, and sulfides of iron and copper. These accessory minerals are very minor constituents, generally less than 5 percent of the volume. Tourmaline and beryl are rare in the Plumtree area. Small amounts of beryl were found in the pegmatites of the Henson Creek valley, notably at the Old Black Mine.

The alaskite bodies consist largely of crystals less than 1 inch across (fig. 6), although most bodies contain lenses of coarse pegmatite with crystals 6 inches or more across. Some alaskite bodies have flow structures and cataclastic textures, indicating movement after emplacement, but other bodies are entirely free from these effects. The largest alaskite bodies in the area lie in the southeast near Gusher Knob.

Figure 6

The textures in the alaskite from the old Feldspar Flotation Company pit at Spruce Pine are representative of the variations within the alaskite masses. The relative differences in grain size of the three textural units are emphasized by the knife and keys. The coarse-grained material is approaching the pegmatitic phase with some crystals over 1 inch across. The two finer grained phases have well defined gneissoid structure.

The pegmatitic alaskite bodies are from a few inches to 2,000 feet long and from a few inches to 1,000 feet wide. Large pegmatite bodies like those in the upper reaches of Staggerweed Creek and the large body on Doublehead Mountain are multiple pegmatites involving several intrusive bodies. The bulk composition of the pegmatite is similar to the alaskite (table 8). Plagioclase is generally the predominant mineral even though the ratio of plagioclase to microcline may differ from zone to zone. There are, however, some pegmatites in which potash feldspar predominates, as in the vicinity of Chestnut Mountain on the Newland quadrangle.

Zoning is reflected by variation of composition and texture within the pegmatite. The commonly recognized zones are border, wall, intermediate, and core. Later replacement of fracture filling units may transect the others. In any particular pegmatite certain zones may be missing, but their order is not inverted.

The border zone is generally only a few inches thick and fine grained with crystals under 1 inch long. The dominant minerals are plagioclase and quartz, with or without muscovite. If contamination with the hornblende- or biotite-rich rocks has occurred, garnet may be locally abundant.

The wall zone with crystals generally larger than 1 inch is thicker than the border zone but often of similar mineral composition. Frequently this wall zone contains concentrations (shoots) of good sheet muscovite (fig. 7).

Figure 7

Muscovite sheets (dark crystals) approximately 6 x 8 inches exposed in the wall zone of the pegmatite at the Meadow mine, 1 mile north of Plumtree. Mica is not abundant in the intermediate zone exposed in the roof, at the top of the pillar, where the contact between the wall and intermediate zones is sharp.

The intermediate zone is often small or absent in the pegmatites of the Plumtree area. The chief minerals of this zone are perthitic microcline and plagioclase with minor amounts of muscovite. Rarely is this zone a source of good sheet mica. The usual commercial product of this zone is perthitic microcline in blocks 6 inches or more across.

The core consists of an elongate lens or series of disconnected lenses which roughly follow the center of the pegmatite. The core is generally composed of quartz alone or with large perthitic microcline crystals up to 10 feet in the longest dimension.

The most common fracture filling is biotite in thin books up to 1 foot long or thin quartz streaks up to 10 feet long. Late-stage alteration in parts of the pegmatite commonly resulted in the formation of sericite interstitial to the other minerals and the sericitization of feldspar. The fracture-filling and sericitization appear to proceed outward from the core.

These zonal relationships are consistent with the general observations described by Cameron et al (1950). The best samples of zoned pegmatites exposed in the Plumtree area at the time of this work are those of the Slippery Elm, Meadow, Birch, Beech Bottom, and Charlies Ridge mines.

The petrography and other information about mineral relationships of the pegmatites in the Spruce Pine district are described in detail by Maurice (1940) and Olson (1944). Other works pertaining to the alaskitic rocks and their products are cited in the section on previous works (p. 6).

The alaskite and pegmatite weather to white or light brown soils with small blocks of potash feldspar, quartz, and small sheets or booklets of muscovite. The large alaskite bodies under favorable conditions weather to clay deposits. Most of these deposits lie between 2,550 and 2,750 feet in altitude and were formed by the weathering of old land surfaces near the Toe River.

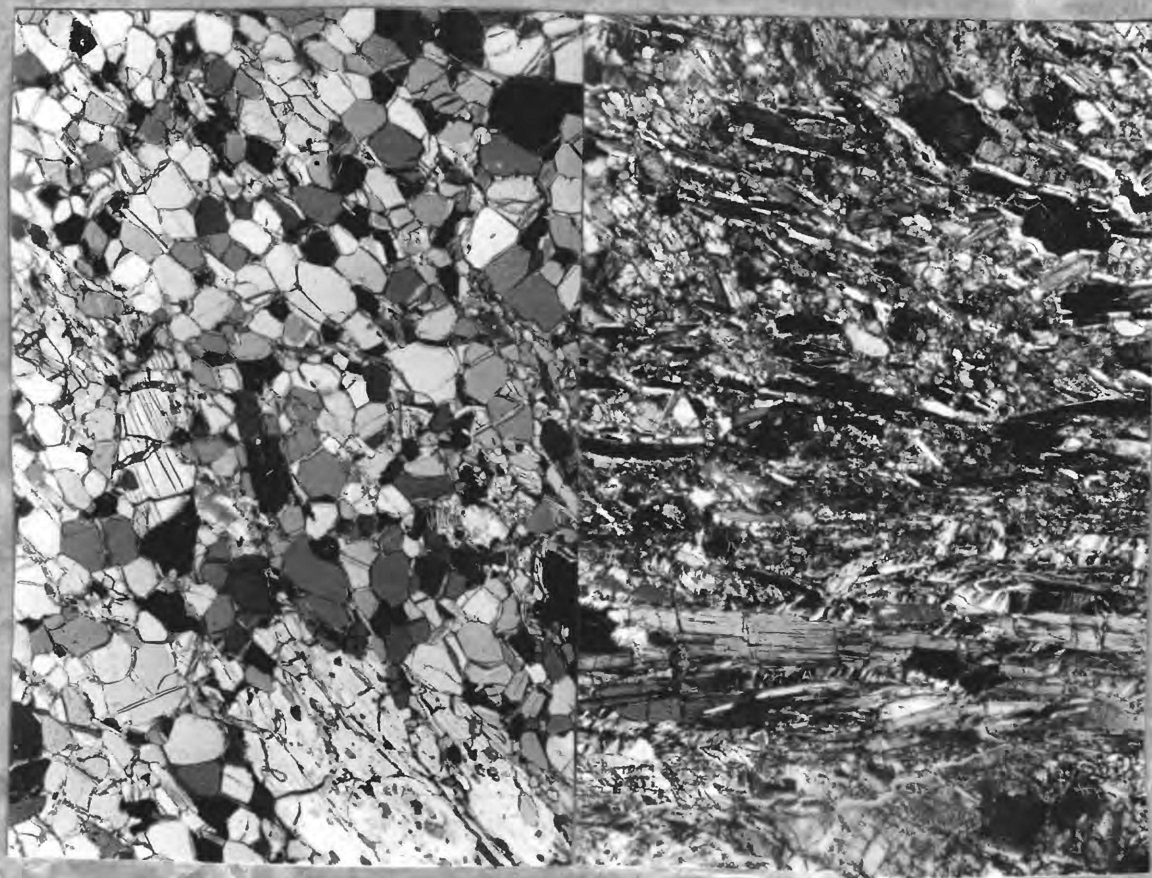
Dunite and associated rocks

The main bodies of dunite and soapstone are located at Frank, near the head of Henson Creek, along Soapstone Branch on the west side of Cane Creek Mountain, and near the mouth of Roaring Creek at Senia.

The green dunite is made up primarily of magnesian olivine (α 1.656, β 1.668, γ 1.690, Mg:Fe approximately 90:10) with accessory amounts of antigorite, enstatite, talc, vermiculite, anthophyllite, chlorite, chromite, and magnetite. These minerals are commonly arranged in zones roughly parallel to the country rock contact. The usual zones, from the wall rock inward include: (1) talc-anthophyllite-serpentine fringe, (2) serpentinized (antigorite) dunite (pl. 18 B), (3) a relatively unaltered granular olivine core (pl. 19 A), although some olivine may have thin serpentine rims. The accessory magnetite and chromite are generally disseminated throughout all the zones.

Hunter and Rankin (1941) present an excellent series of photographs illustrating the progressive alteration of fresh to serpentinized olivine. In this same paper, petrographic analysis of the olivine core of the Frank body show the composition to be 70-80 percent ferruginous enstatite, 5 percent chlorite, less than 1 percent chromite, with minor quantities of antigorite and talc. These figures appear average for the cores of other dunite bodies examined in the area.

The cores of the dunite bodies are generally undeformed although some evidence of deformation (shear planes, slickensided surfaces) may appear in the outer zones and extend part way into the core. Plate 19 B illustrates the effect of shear on the core of the body. The olivine is granulated and the interstitial spaces are filled by serpentine. Amphiboles may be developed and foliation is commonly produced.



A B

Plate 19

A. Granular olivine and ferruginous enstatite (elongate grains with cleavage) with minor interstitial serpentine (X 16, X nicols) from the core of the Frank body, Avery Co.

B. Sheared altered dunite (X 30, X nicols) from the outer portion of the core of the Henson Creek dunite body, in Mitchell Co. Shear planes and foliation are oriented left to right. The olivine is granulated and fibrous serpentine fills the interstices.

The mineral composition of the soapstone is variable, but the chief constituents generally include talc, amphibole, chrysotile, and chlorite. These bodies are generally found along the trends of other ultramafic bodies. Transition varieties, from fresh dunite to completely talcose and serpentinized soapstone, have been observed.

Dunite and soapstone bodies weather to a dark brown soil which supports little vegetation. The talcose soapstone bodies are so resistant to weathering that they stand as mounds 10 to 12 feet high. During the weathering of the contact alteration zones between pegmatite and dunite, the phlogopite is altered to vermiculite. In all the deposits of the area it has been found that the vermiculite grades into unaltered phlogopite at depths from 10 to 40 feet below the surface.

Diabase

Unmetamorphosed thin black diabase dikes cut across the pegmatites and the country rocks in the Plumtree area. Dikes which crosscut pegmatite can be seen in the Elk and Slippery Elm mines in Avery County.

At the Slippery Elm mine, along Plumtree Creek, the dike averages 10 inches thick (fig. 8). It is traceable through the workings on a N. 30° W. strike with a 75° dip to the northeast. The texture is diabasic with zoned plagioclase (An_{50}) laths as long as 1 millimeter with interstitial augite grains averaging 0.6 millimeter across (pl. 20 A).

The dike at the Elk mine is a diabase porphyry (pl. 20 B). The phenocrysts are euhedral augite grains (0.3 millimeter across) and plagioclase (An_{50}) laths 1 millimeter long and 0.1 millimeter wide in a fine-grained groundmass half feldspar and half augite. The corroded phenocrysts comprise 25 percent of the rock; plagioclase phenocrysts dominate over augite, 3:1.

Figure 8

A 10-inch thick diabase dike cuts the pegmatite in the Slippery Elm mine, along Plumtree Creek. The dike appears to be a fracture filling, but there is no vertical displacement of the wall rocks. Notice the rolls in the contact of the pegmatite with the underlying biotite gneiss.

A

B

Plate 20

A. Diabase dike (X 16, X nicols) illustrating the typical texture of the plagioclase laths encroaching on the earlier augite crystals. Locality: Slippery Elm mine, Avery Co.

B. Diabase porphyry (X 16, X nicols) with euhedral phenocrysts of augite and albite-twinned plagioclase (An_{50}) laths in a fine groundmass. The dusty grains of plagioclase in the upper left are part of the thin alteration zone in the pegmatite formed by the contact action of the diabase. The reaction of the pegmatite with the diabase has caused the augite phenocrysts near the contact to be altered to aggregates of biotite and chlorite. Locality: Elk mine on Middle Elk Ridge, Avery Co.

Structural geology

Large scale structure

The broad structural pattern of the Spruce Pine district appears to be a southwest-plunging asymmetrical synclinorium about 20 miles wide with the steepest limb on the northwest. The axis of the synclinorium passes approximately through the center of the district. The mica and hornblende rock complex is rimmed and underlain by Cranberry gneiss.

Figure 9 shows the general large scale structural features of the Plumtree area. The northeast end of the synclinorium can be divided into three major parts or zones: zone I on the northwest is characterized by northeast-trending inclined isoclinal folds with southeast dips; zone II on the southeast includes an area of rocks with low dip; zone III is the complex central core between zones I and II. Zones I and II have an indistinct boundary in the extreme northeast where the two zones coalesce along the rim of the major structure.

The main structural feature of zone I is the steeply inclined isoclinal folding. The folds have been overturned to the northwest. The rocks in these folds strike northeast and dip steeply 45° to 90° to the southeast. The rocks of this zone are mostly hornblende and mica gneiss, with hornblende rocks predominating in the extreme northeast.

Zone II is characterized by layers of mica schist with variable strike and gentle dips, generally under 30°. This variability of strike and dip makes the large structures more obvious in zone II than in either of the other zones. The largest structures are synclines with axes several miles long in the vicinity of Little Elk Mountain, and Spear Tops, southwest of Plumtree.

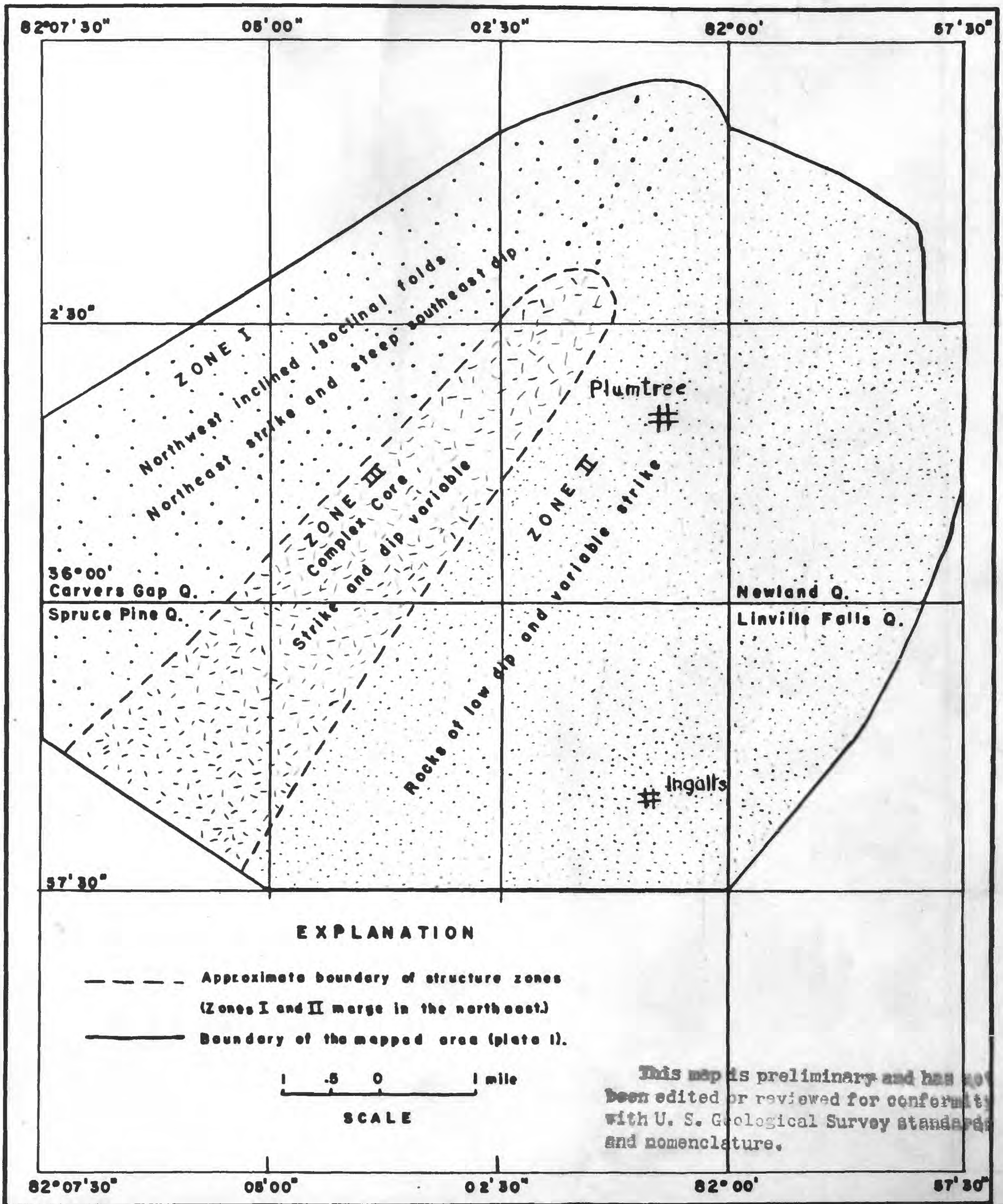


Fig. 9. A generalized structure map of the Plumtree area, Spruce Pine district, N.C. 47a

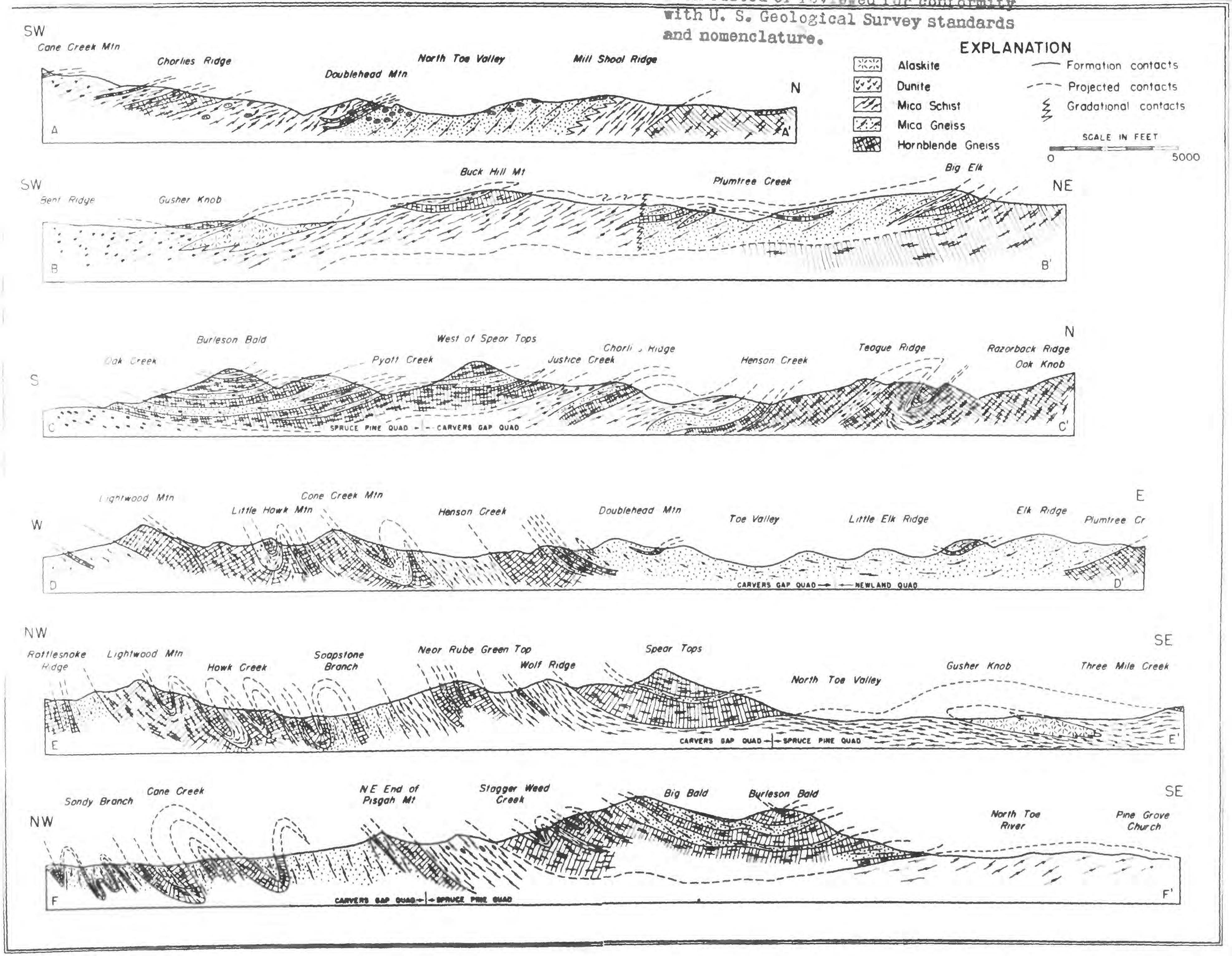
Zone III which occupies the middle of the Plumtree area from Ledger to Doublehead Mountain has a great complexity of structure which may represent the core of the major synclinorium. Near Ledger there is a syncline which disappears to the northeast in an area of predominantly hornblende rocks. Farther to the northeast near Staggerweed Creek, mica schist interfingers with the hornblende rock in a very contorted pattern (pl. 1). Many pegmatites are found in this steeply and irregularly dipping mica schist complex. The largest pegmatite in the Plumtree area lies in this zone near High Knob.

The geologic sections (fig. 10) show the general structure of the Plumtree area. The notable feature of sections A-A' and B-B' is the gradational contact of the mica gneiss and schist on Mill Shoal Ridge and between Buck Hill and Plumtree Creek respectively. Sections B-B' and C-C' were taken roughly parallel to the axis of the synclinorium and clearly show the southwest plunge of this structure. Sections D-D', E-E', and F-F' essentially cut across the axis of the synclinorium and show the elements of the three structure zones described in the preceding paragraph.

There appears to be no large scale faults in the area, although mappable shear zones are known in other parts of the mining district, notably along White Oak Creek near Bakersville and on Tempa Mountain near Spruce Pine.

Joints are numerous, especially in the hornblende rocks and irregular fractures and expansion joints parallel to the outcrop surfaces are common.

This map is preliminary and has not been edited or reviewed for conformity with U. S. Geological Survey standards and nomenclature.



Stratigraphic implications of the structure

With the aid of geologic section E-E' (fig. 10) it is possible to make a generalized stratigraphic sequence of the rocks in the Plumtree area. The mica schist exposed in the North Toe valley at the southeast end of the section is a part of the large body of this rock which is exposed almost continuously for 15 miles from the Crabtree Creek area in southwestern Mitchell County to Wolf Ridge and Little Henson Creek, northwest of Spear Tops. It may be designated an Upper Mica Schist with a thickness of about 2,500 feet. Overlying this rock in the Spear Tops area is a body of hornblende gneiss with some mica gneiss which may be called an Upper Hornblende Gneiss, calculated to be over 2,000 feet thick because the section is incomplete at the top. Tongues of this hornblende gneiss appear on Gusher Knob and Buck Hill Mountain.

Below the Upper Mica Schist is roughly 1,000 feet of Middle Hornblende Schist exposed near Rube Green Top. Directly below this layer is 1,000 feet of Lower Mica Schist which grades into mica gneiss and hornblende gneiss in the south.

The Lower Hornblende Gneiss with some mica gneiss and schist extends from northwest of Long Hollow to the northwest edge of the section and is over 2,000 feet thick. South along the strike of this band the relative abundance of rock types is reversed and the mica gneiss predominates. This leads to the estimate that the stratigraphic thickness of metamorphic rocks exposed in the Plumtree area is more than 10,500 feet. In summary, the column is:

	Feet
Upper Hornblende Gneiss (Gusher Knob, Spear Tops..............	2,000+
Upper Mica Schist (wide distribution in the area).............	2,500
Middle Hornblende Gneiss......................................	1,000
Lower Mica Schist (grades to hornblende and mica gneiss to the south..	1,000
Upper Mica Gneiss (with minor hornblende gneiss)..............	2,000
Lower Hornblende Gneiss (plus bands of mica gneiss and schist, to the south mica gneiss predominates with some hornblende gneiss)..	2,000+
Total............	10,500+

Small scale structure

Small scale structural features in the metamorphic rocks include foliation, lineation, minor folds and minor faults as well as graded bedding. These features are widespread and commonly all of them may be seen on a single outcrop.

Foliation

An universally well-developed foliation is the most conspicuous structural feature of the metamorphic rocks. The foliation planes, defined by the orderly arrangement of the elongate minerals and the (001) planes of the micas, are parallel to the layers of varying mineral compositions. These foliation planes or "s" planes appear to fit the fabric of Class I (Turner, 1948, pp. 277-278) where foliation is parallel to a single set of slip planes (ab in fig. 11). When foliation has been developed on a single set of planes which are parallel to compositional layers it is probable that slip took place along pre-existing planes of weakness such as original bedding planes. The resulting structure may be called a "bedding foliation". This foliation in the Plumtree area follows the shape of the folds, therby indicating that the rocks were folded contemporaneously with metamorphism (fig. 12).

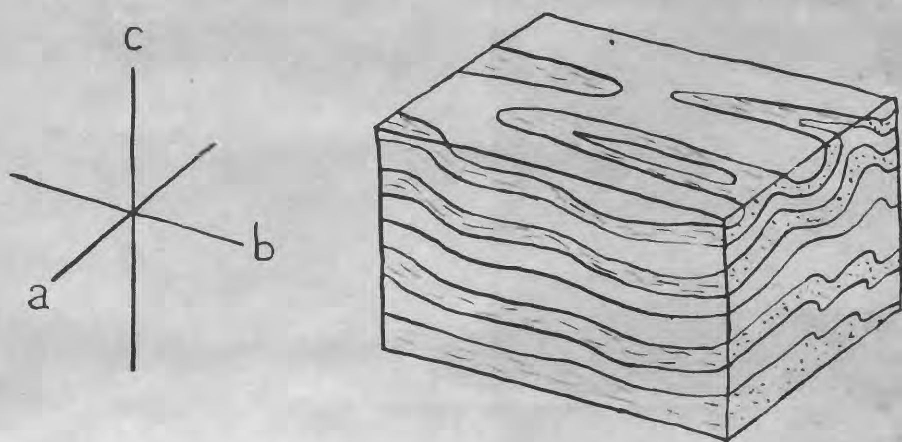


Figure 11. Diagram to illustrate the relation of foliation and lineation to the fabric axes, a, b, and c. The block diagram (B) shows the typical fabric elements found in the rocks of the Plumtree area. The foliation has developed parallel to the layering (plane ab) along which slip has occurred. The foliation plane ab is therefore an "S" (slip or shear) plane. The linear elements are parallel to the "b" axis. Under these conditions movement was probably in the direction of the "a" fabric axis. An exception to this set of conditions is met in the lineation of slickensides on fault planes. In this case, the lineation is parallel to the direction of movement which coincides with the "a" axis.

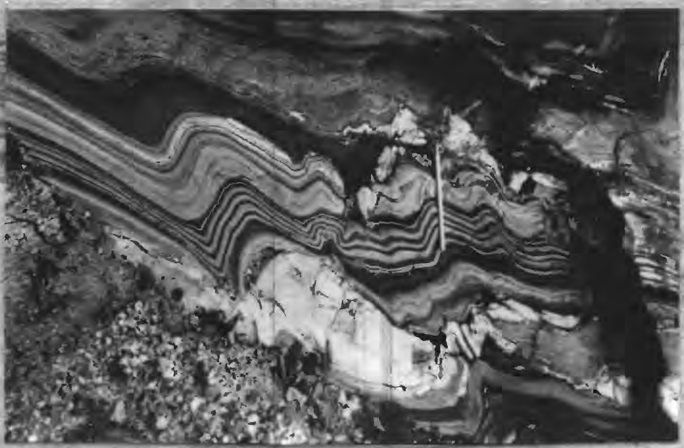


Figure 12

Intimately interlayered hornblende (darker layers) and mica (lighter layers) rocks have been differentially and complexly folded in the plastic state. The foliation wraps around the crests of the folds in a local disturbance which dies out within a foot above the massive white quartz. This photograph was taken at the exposure along Crabtree Creek 0.5 mile north of its intersection with U. S. route 19E about 4 miles west of Spruce Pine.

Lineation

The lineation in the metamorphic rocks of the area is of types: (1) dimensional parallelism of prismatic and platy minerals, usually hornblende and mica, respectively (2) linear crenulations, grooves, or drag folds in the S-planes.

The linear elements appear to be at right angles to the movement direction of the S-planes. If this is true, the lineation coincides with the axis of contemporary major folding (the tectonic axis of regional deformation) and therefore also with the "b" fabric axis.

An exception to the above example is the interpretation of the lineation associated with slickensides on minor fault planes. Here the linear elements are parallel to the direction of movement which coincides with the "a" fabric axis (fig. 11).

Minor folds

Minor folds with axes plunging south or southwest at low angles reflect the major structural trends of the area. Since the foliation follows the pattern of the fold, the two features were probably developed simultaneously. This implies that the deformation was accomplished by flexural slip and not slip alone which would result in a foliation parallel to the axial plane of folds. So called "axial plane" foliation has not been found in the area.

Tiny chevron folds, less than 1 inch from crest to crest, as well as irregular crenulations of the foliation, are especially abundant in the mica rocks, the more incompetent layers in the sequence.

Other minor folds present no definite relation to the regional deformation. These folds might be interpreted as minor adjustments of the rocks in response to local conditions, such as differential expansion and contraction of neighboring layers or groups of layers of different composition under the influence of locally variable temperature and pressure conditions. Adjustments of this type, while the rocks were in a partly plastic state, might explain a fold (fig. 13) which affects only a few layers of the sequence. Some minor folds and distortions of the layers in the plastic country rocks presumably were caused by local pressures exerted by pegmatites during emplacement.

Other small scale structures

Suggestion of graded bedding is widespread in both the mica and hornblende rocks. There are greater concentrations of mica or hornblende toward the top or bottom of the individual layers. There seems to be no systematic increase or decrease of the grain size within these concentrations. Several layers marked X on figure 13 have this suggestion of graded bedding. The discontinuity of outcrops throughout most of the area makes it impossible to work out larger structures based on this information.

Many randomly oriented minor faults whose planes of movement are marked by slickensided surfaces may be coated with manganese oxides or micaceous minerals. Measurable displacement is generally only a few inches and the cumulative effects of these faults appear small.

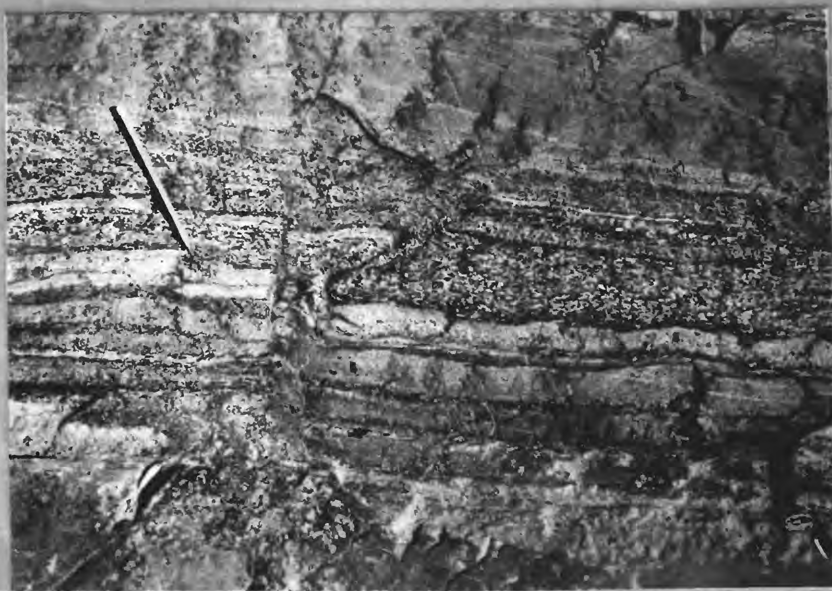


Figure 13

A close-up of a local fold and rupture in the hornblende rock sequence in the bed of Plumtree Creek 250 feet north of altitude 3,450 feet. The layers marked X have faint graded bedding where the light and dark constituents seem to be more concentrated in different parts of the bed.

Structural control and distribution of the alaskite and pegmatite

Local emplacement control of the alaskite and pegmatite bodies is determined by the structure and kind of host rock. The schists and gneisses with a high mica content are the most favorable host rocks. The planes of weakness between the layers and mica folias provided easy access for the intrusion of igneous material which commonly accumulated in the troughs or crests of folds. Most of the alaskite and pegmatite bodies in the mica rocks are concordant with the layers and foliation (figs. 8 and 14), but crosscutting bodies occur—on Elk Ridge, in the road cut along U. S. route 19E about 0.5 mile north of the Toe River bridge at Plumtree, and in the road cut along the Henson Creek road west of the curve at the junction with the Little Henson Creek road.

Pegmatites in the hornblende rocks are more commonly discordant with the layers and foliation of the country rocks than are those in the mica rocks. Joint planes and fractures are the main lines of accessibility for the entering pegmatitic fluids. Conformable pegmatites in the hornblende gneiss generally follow contacts between the layers of the host rock.

Figure 14

The essentially concordant relationships of pegmatite bodies with the enclosing mica gneiss host rock as seen in an abandoned scrap mica pit along the north side of U. S. route 19E 3.5 miles west of Spruce Pine. The roll of the hanging wall contact of the body in the upper left is the type of structure with which "shoots" of sheet mica commonly are associated.

The host rock and structural control of the alaskite and pegmatite emplacement explains the distribution of these bodies. The concentration of valuable pegmatites in the Hanson Creek area is linked to the presence of favorable mica rock host rocks and a favorable structural position i.e. up the plunge of the synclinorium, the base of which is the presumed source of the igneous material. This favorable host rock, furthermore, is overlain by a thick sequence of hornblende rocks which formed an essentially impermeable cap to the mica rocks below. In addition, this upper hornblende unit (p.) is farthest from the presumed source of the pegmatites—thus, the area essentially barren of pegmatites located between Burleson Bald mountain and Spear Tops is also explained. The area of mica schist between Pine Knob and Spruce Pine mountain appears barren because the low dip of the country rock and the less rugged topography are not conducive to the exposure of many probably conformable alaskite and pegmatite bodies.

Metamorphism

Metamorphic facies

The Carolina and Roan-type rocks belong to the amphibolite facies resulting from middle to high-grade regional metamorphism. All these rocks are assigned to the staurolite-kyanite subfacies (Turner, 1948, p. 81) of amphibolites and isogradic rocks deformed by high pressure and shearing stress. Kyanite and staurolite, not abundant in the Plumtree area, are the characteristic minerals, but almandite, hornblende, plagioclase, and the micas are common in rocks of the subfacies. These rocks are a part of the subfacies which is deficient in potash as compared to alumina, magnesia, and ferrous oxide. For this reason potash feldspar is absent or present only in minor amounts. The role of water is important because potash feldspar and any staurolite, kyanite, or almandite will react with it to form mica. In this way the chemical constituents of potential staurolite, kyanite, or almandite have combined to form mica in which all the available potash is "fixed". When potash is no longer available, "excess" alumina, silica, and ferrous iron will form the three critical minerals of the subfacies. The detailed chemical relationships of potash feldspar, mica, kyanite, staurolite, and almandite in the metamorphic rocks of Duchess County, N. Y. have been described by Barth (1936, pp. 817-822).

Retrogressive metamorphism

Retrogressive metamorphism is the mineralogical adjustment of metamorphic rocks to conditions of temperature and pressure prevailing after the highest grade of metamorphism has been attained, but excluding those changes caused by weathering. This adjustment results in the formation of minerals more stable at temperatures and pressures below the maximum conditions involved in the metamorphism. The new minerals are generally more hydrous than the pre-existing ones. This is essentially the view taken by Schwartz and Todd (1941).

The application of this broad definition means that mineralogical changes like the alteration of kyanite to muscovite (pl. 7 B), chlorite rims on garnet, the scattered effects of hydrothermal alteration along shear zones, and the alteration of hornblende to chlorite and biotite caused by the contact action of pegmatite on the hornblende rocks are indications that retrogressive metamorphism has taken place in a minor way.

Metamorphic differentiation

According to Turner (1948, p. 138), most geologists consider metamorphic differentiation to be the solution and redeposition of the chemical components of rocks during metamorphism. It is, therefore, a result of diffusion which causes a parent rock to split into contrasting fractions. By this definition, the differentiation is caused mostly by chemical movements involving the generally recognized principles of solution, concretion, and enrichment of the most stable constituents. These movements are supplemented by mechanical adjustments in the form of crystal gliding or rotation caused by response to changing conditions of pressure.

The development of porphyroblasts and the segregation of minerals like quartz, feldspar, mica, and epidote into discontinuous streaks can be explained by these mechanisms which utilize materials readily available within a few millimeters.

The processes of metamorphic differentiation are probably not the sole cause of the intimate interlayering of the compositionally different rocks and the structure within them. Although these processes may have accentuated the difference between some layers by selective action, it is doubtful that the continuity of layering and the great range of mineral composition in adjacent layers would be formed in this way.

Origin of the metamorphic rocks

Cranberry gneiss

The white to gray Cranberry rocks were considered by Keith (1903, 1907) to be an Archean granite which intruded the overlying mica and hornblende rocks. Reconnaissance of the perimeter of the Spruce Pine district has revealed that the Cranberry is banded gneiss consisting of distinct and mineralogically different layers. The crosscutting relationships expected between a pluton and host rock were not found; in fact, Cranberry type layers are intercalated with the hornblende and mica rocks in the vicinity of the contact. Massive phases of the Cranberry, like the one exposed on the road to Mount Pleasant Church one mile northwest of Crossmore, are rare, but they can be traced into the common banded types.

The layered character, the lack of regional crosscutting relationships, and the interlayering with the mica and hornblende rocks suggest that the Cranberry rocks are of sedimentary origin—derivatives of arkosic sediments.

Carolina-type rocks

Because of the field relationships--intimate interlayering of compositionally different rocks, the structures within the layers, the distribution pattern of the mica rocks, and their composition, it is agreed with Keith (1903, 1905, 1907) that the rocks of the Carolina-type are of sedimentary origin.

The chemical composition of four kinds of mica rocks are listed in Table 6. Analysis 1, considered typical of the large mica schist unit exposed from the Crabtree Creek area northeast of Spruce Pine and Plumtree, is similar to the composition range of many shales. The common mica gneiss (analysis 2) comes within the range of many sandstones, perhaps of the nature of a graywacke. Analysis 3 is typical of the mica gneiss which approaches the composition of an impure quartzite. The presence of sulfur and organic matter in analysis 4 is suggestive of a sedimentary origin, perhaps from a graywacke.

Roan-type rocks

Because of the great variety of composition of the hornblende layers, as well as their structure and distribution, it is concluded that the Roan-type rocks are of sedimentary origin. They are intimately interlayered with the originally sandy and shaly Carolina rocks. The hornblende rocks, therefore, may represent the metamorphosed equivalent of impure carbonate layers in the sedimentary sequence.

Table 6

Analyses and Norms of Carolina-type rocks

	1	2	3	4
SiO_2	63.14	71.13	82.46	62.01
Al_2O_3	16.30	13.14	8.60	14.68
Fe_2O_3	2.86	.98	.19	1.43
FeO	4.26	3.34	1.76	4.23 1/
MgO	2.62	1.51	1.51	2.28
CaO	1.90	1.95	.74	4.51
Na_2O	2.30	4.32	2.64	2.60
K_2O	3.42	1.52	1.16	3.08
H_2O	.30	.04	.06	.09
H_2O^+	1.74	.61	.42	.73
TiO_2	1.06	.86	.38	.69
CO_2	.03	.02	.01	.49
P_2O_5	.11	.22	.06	.25
S		.39		2.19
SO_3				
MnO	.15	.07	.03	.19
		100.10		99.45
Less O for S		.20		1.09
Total	100.20	99.90	100.02	98.36 2/

	1	2	3	4
Q	27.20	28.20	56.34	15.36
or	20.02	15.01	6.67	17.79
ab	19.39	36.15	23.91	30.39
an	9.45	8.90	3.61	14.73
C	5.41		1.63	
di		.46		2.22
hy	10.46	6.64	6.21	5.82
mt	4.18	1.39	.23	2.09
il	1.98	1.52	.61	1.37
pr		1.54		8.09
cc				1.10

1. Oligoclase-biotite-muscovite-quartz schist from along U. S. route 19E at the first bridge over the North Toe River in Avery Co., north of Spruce Pine, North Carolina. R. H. Stokes, analyst, U.S.G.S. laboratory, Denver, Colo.

2. Oligoclase-quartz-biotite gneiss, a common mica gneiss from Doublehead Mountain, Avery Co., North Carolina. R. H. Stokes, analyst.

3. Oligoclase-quartz-biotite gneiss, more quartzose than sample 2 above, from 300 feet north of the junction of Plumtree Creek road, which is just north of Plumtree, Avery Co., North Carolina. R. H. Stokes, analyst.

4. Microcline-quartz-biotite-oligoclase gneiss with sulfides and organic matter from 2,200 feet S. 50° W. of the junction of the Henson and Little Henson Creek road, Avery Co., North Carolina. R. H. Stokes, analyst.

1/ Because of the presence of acid soluble sulfides, the ratio of FeO to Fe_2O_3 is not reliable.

2/ Large amounts of organic matter present.

Table 7 lists the analyses of four kinds of Roan rocks. Analysis 1 is typical of the monomineralic hornblende schists. A calculated original rock was 57 percent carbonate if half of the iron, all of the magnesia, and all of the lime (plus 10 percent to cover possible losses in metamorphism) were originally associated with carbon dioxide. The other half of the iron was 3 percent of the rock as mixed oxides. The aluminum occurred in clays totaling 15 percent of the rock and the remaining 25 percent silica occurred as quartz. Compositions also suggestive of impure carbonate rocks are indicated by analyses 2 and 3. Furthermore, the occurrence of quartz-rich rocks with hornblende also points to a sedimentary origin. Sandy carbonate rocks might be expected in association with the original sandstones and shales of the Carolina rocks.

The hornblende-biotite rock (analysis 4) is perhaps one of the most significant in the area for Wiseman (1934, p. 397) in describing the epidiorites (metamorphosed igneous rocks with hornblende) of the central and southwestern Scottish highlands said, "The presence of biotite in an amphibolite from the kyanite zone is a good indication of its sedimentary origin, for so far no authentic epidiorites with biotite have been recorded from this zone".

The possibility that volcanic material may be the source of the hornblende rocks cannot be discounted, but the intimate interlayering of many hornblende rocks with micaceous layers from less than 1 inch to several tens of feet in thickness calls for volcanism on a grand scale. The great variation in composition of the hornblende rocks is against this mode of origin although there was the possibility of contamination. Perhaps some of the layers were pyroclastic material, but these cannot be distinguished from the other meta-sedimentary layers.

Table 7

Analyses and norms of Roan-type rocks

Analyses

	1	2	3	4
SiO_2	46.63	50.28	49.58	48.03
Al_2O_3	13.54	16.11	16.11	15.62
Fe_2O_3	2.32	1.46	1.33	3.52
FeO	8.13	8.65	8.42	8.29
MgO	14.33	7.76	7.42	6.51
CaO	11.24	9.99	11.47	9.33
Na_2O	1.17	2.94	2.84	2.88
K_2O	.14	.45	.42	1.61
H_2O	.02	.09	.03	.08
H_2O+	2.08	1.43	.79	1.47
TiO_2	.27	.54	.99	2.11
CO_2	.03		.23	.01
P_2O_5	.05	.18	.19	.32
S			.11	
MnO	.19	.18	.17	.19
			100.10	
Less O for S			.06	
	100.14	100.06	100.04	99.97

	1	2	3	4
Q				
or	.56	2.22	2.22	9.45
ab	9.43	24.63	24.10	24.63
an	31.41	29.75	30.02	24.74
di	10.62	16.38	19.97	16.20
hy	16.86	12.74	8.00	11.98
ol	15.97	9.81	9.68	.64
mt	3.25	2.09	1.86	5.10
il	.61	1.06	1.98	3.95
ap			.34	.67
cc			.50	
pr			.35	

1. Hornblende schist near altitude 2,593 feet along N. C. route 80, east of Kona, Mitchell Co. R. H. Stokes, analyst, U.S.G.S. laboratory, Denver, Colo.

2. Hornblende-andesine gneiss S. 70° W. 200 feet from the summit of Copperas Bald near Frank, Avery Co. R. H. Stokes, analyst.

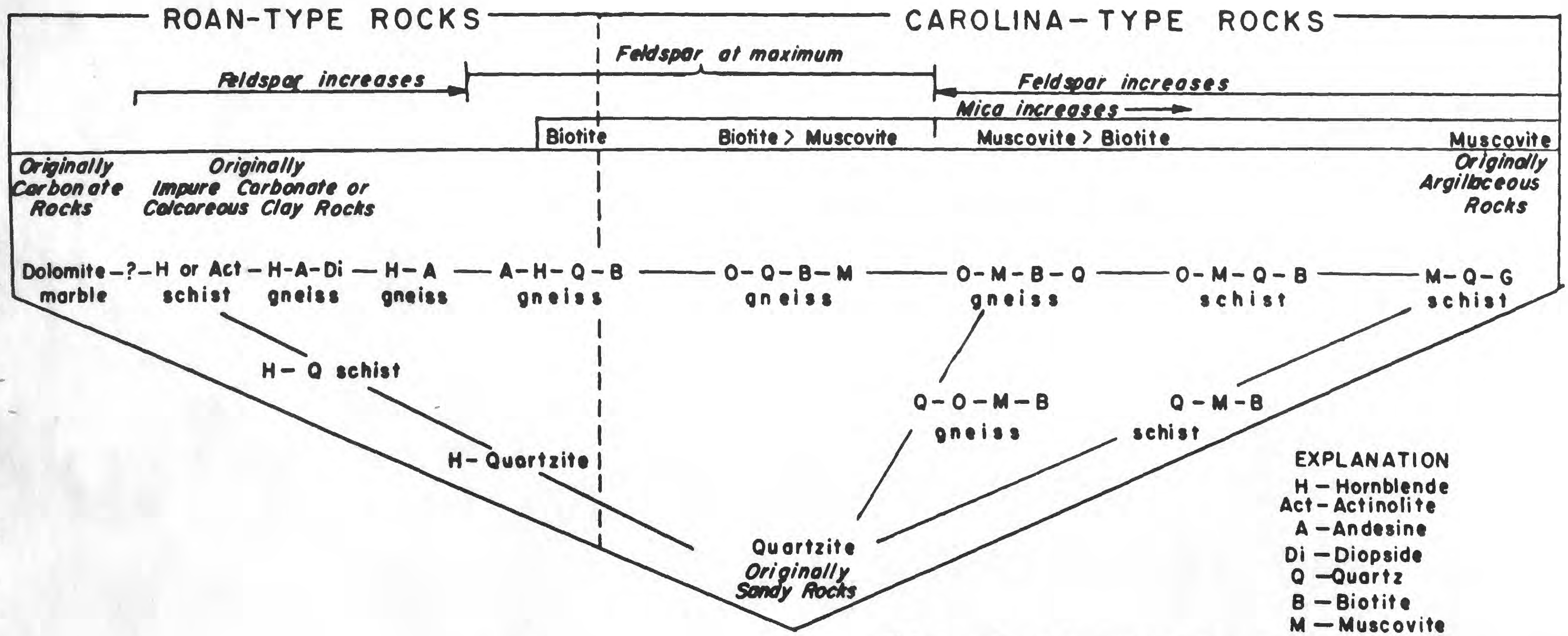
3. Andesine-hornblende-garnet-diopside gneiss N. 60° E. 1,800 feet from altitude 3,135 at Frank, Avery Co. R. H. Stokes, analyst.

4. Hornblende-plagioclase-biotite gneiss 700 feet west along N. C. route 197 from altitude 2,169 feet at Deyton Bend, Mitchell Co. R. H. Stokes, analyst.

Although Keith (1903, 1905, 1907) considered the hornblende rocks to be of intrusive igneous origin, there is little evidence to support this hypothesis mainly because crosscutting relationships between the hornblende and mica rocks are absent. To suppose that all of the intrusive bodies are sills or that all of the crosscutting structures are unexposed is most unlikely.

G. W. Stose and A. J. Stose (1949, p. 315) have considered the hornblende rocks of the Lynchburg gneiss to be the flows and sills in an originally sedimentary sequence. The use of the term Lynchburg in this area is therefore deemed inappropriate because it appears that the hornblendic rocks are not of igneous origin. The Spruce Pine district, furthermore, is separated from the type locality by 200 miles and many rocks, the detailed geology of which is unknown.

Figure 15 illustrates the ideal relationship of some of the metasedimentary Carolina-type and Roan-type rocks. The rare dolomite marble (Olson, 1944) does not crop out in the Plumtree area but it is included with the Roan-type rocks because of its composition and field relationships--conformable layers on strike of hornblende rocks.



This map is preliminary and has not been edited or reviewed for conformity with U. S. Geological Survey standards and nomenclature.

Fig. 15 - Idealized relationships of some Carolina- and Roan-type rocks.

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Origin of the igneous rocks

Alaskite and pegmatitic alaskite

These intrusive bodies need not have moved upward from great depth. The Cranberry gneiss which underlies the great hornblende and mica rock sequence may be the source of the alaskite. The depth at which the Cranberry gneiss lies in the central part of the synclinorium may have been sufficient to yield the added temperature increment necessary to mobilize its silicic portions which then migrated and were emplaced to the northeast up the plunge of the structure. Analyses of alaskite and pegmatitic alaskite are compared (Table 8) with a calculated composition of a common type of Cranberry gneiss. The field relationships and the calculations afford a basis for this speculation.

The reasons why some pegmatites are zoned and others are unzoned is not clear, but from the zoned pegmatites it is concluded that the zones represent successive layers of crystals deposited on the walls of the chamber enclosing the body of pegmatitic fluid and that the body formed primarily by fractional crystallization.

The pegmatites of the Spruce Pine district are chemically simple when compared to pegmatites of many other areas. They contain negligible amounts of lithium, boron, beryllium, and fluorine. This lack of certain minor constituents which are so effective in promoting crystal growth may partly explain the general lack of zoning in the pegmatites of the district as well as the restricted number of zones where they do occur.

Table 8

Chemical analyses of alaskite, pegmatite, and calculated composition of Cranberry gneiss

	A	B	C
SiO_2	74.9	75.26	73.0
Al_2O_3	14.9	14.92	15.0
Fe_2O_3	0.33	0.28	
FeO + MgO			1.0
CaO	1.0	1.10	.5
K_2O	4.7	4.19	6.2
Na_2O	4.0	4.2	3.5
H_2O			.3
Loss	0.2	0.28	
	100.03	100.23	99.5

A 500 tons of alaskite from the Davis Quarry, Minpro, North Carolina (Olson, 1944, p. 23).

B 500 tons of selected pegmatite from Deer Park No. 5 mine, Penland, North Carolina (Olson, 1944, p. 23).

C Calculated analysis of a common type of Cranberry gneiss with a mode of 30 percent quartz, 30 percent microcline, 30 percent albite (An_8), 5 percent muscovite, 5 percent biotite.

Dunite and associated rocks

Because the dunite bodies probably were not melts (Bowen and Tuttle, 1949), they must have been intruded as a mush of olivine crystals. At higher elevations in the crust, serpentine interstitial to the olivine could be stable and form a lubricant to assist the movement of the dunite. Additional hot water coming along the weakest zone (i.e. the contact with the country rock) altered the olivine to serpentine, talc, and anthophyllite. If the altered solutions were of sufficient quantity and contained enough silica, the ultramafic body could be worked over entirely to soapstone. It is, therefore, possible that apparently small soapstone bodies are actually caps of larger dunite masses below, or that they represent the last of a dunite body which was altered and gradually dissipated as it moved through the enclosing rocks.

It has been suggested (Parker, 1953) that the soapstone rock was derived from the hornblende gneiss. There is evidence to oppose this idea: (1) the ultramafic bodies frequently cut across mixed mica and hornblende gneiss, (2) no gradation between the ultramafic rock and the hornblende gneiss has been observed, (3) where later pegmatite has come in contact with the hornblende gneiss, biotite is the common product, not talc or serpentine, (4) the regional distribution of similar ultramafic and soapstone bodies outside of the Spruce Pine district in areas where hornblende rocks are absent.

Age relationships

The oldest rocks of the area are the metasedimentary rocks of the Cranberry gneiss, and above this unit lies the thick sequence of Carolina-type and Roan-type metasedimentary rocks. The field relationships suggest that all of these rocks were deposited in one continuous period of sedimentation. If any of the Roan-type rocks are volcanic or intrusive, then this activity predates regional metamorphism.

King (1950) suggests that the Carolina-type and Roan-type rocks may be contemporaneous with the Ocoee and Talladega series to the southwest, which would place their estimated age as late pre-Cambrian (500-600 million years?).

The ultramafic intrusive rocks are presumed to be associated with the early phases of the regional metamorphism. Subsequent to this activity, the metamorphism was reaching its peak with the recrystallization and deformation of the original rock sequence.

The alaskite and associated pegmatites were introduced while the country rocks were in a plastic state. A possible source of this material is the mobilization of material at the base of the sequence, notably the rocks of the Cranberry gneiss. After the entry of the alaskite, cooling and minor adjustments took place in the rocks as reflected in their cataclastic textures: fractured garnets, splintered micas, and bent and broken twin lamellae in plagioclase. Then followed the development of the late shear zones with accompanying hydrothermal alteration of the affected rocks.

Attempts have been made to determine the age of the pegmatites by the study of their radioactive minerals. The unpublished results of the most recent determination placed the age of the pegmatites in the Spruce Pine district at 370 ± 10 million years (J. L. Kulp, personal communication). This indicates that the pegmatites were probably emplaced during the early Paleozoic era. It is possible to speculate, therefore, that the regional metamorphism in the Spruce Pine district was synchronous with the well known Taconian disturbance farther north.

A few unmetamorphosed diabasic dikes, like those of the Slippery Elm and Elk mines, were intruded after the emplacement of the pegmatites and the regional metamorphism. Intrusive rocks of this type, observed over large parts of the eastern United States, have been assigned to the Triassic period.

Cenozoic time evidently was consumed in erosion and uplift along with some stages of essential stability which allowed deep weathering of the rocks. This weathering was instrumental in the formation of the exploitable clay deposits of the area.

Notes on economic geology

The important mineral products of the Spruce Pine district are derived primarily from alaskite, pegmatite, and ultramafic bodies. The alaskite and pegmatites yield feldspar, scrap and sheet mica, quartz, kaolinite, and halloysite, together with small quantities of columbite-tantalite, beryl, rare earth minerals, and uranium minerals. The ultramafic bodies yield dunite, soapstone, asbestos, vermiculite, and chromite. The mica schist has been mined for scrap mica in places where it is soft. Kyanite-bearing mica gneiss and schist have been mined in the western part of the district. The hornblende gneiss has been used for crushed stone and for building stone.

Detailed accounts of the occurrence of each of these economically valuable minerals have been given by other workers and will not be repeated here.

Alaskite and pegmatitic alaskite

Feldspar

During the last decade the mineral industry in the Spruce Pine district has experienced a mechanical revolution. Prior to 1940, hand cobbed perthitic microcline from the larger potash-rich zoned pegmatites was a major commodity. Since 1940, several companies have begun milling large tonnages of alaskite. By means of froth flotation feldspar, quartz, mica, and garnet can be separated to form a product of good quality for the ceramic and glass industry. Hand cobbing of feldspar has diminished greatly and is continued only for those customers who need a product of higher potash content than is normally produced by alaskite flotation. Hand cobbed microcline is either ground and sold directly or is used to "sweeten" the flotation mill product.

The characteristics which make an alaskite body good raw material for a flotation mill are: (1) unweathered rock, (2) low iron (biotite and garnet) content, (3) mineralogical uniformity, (4) high potash content, (5) large sized body, at least 1,000,000 tons. Mineralogical uniformity is probably the most important criterion because the flotation and milling can be set to cope with almost any one set of conditions, but if these conditions are constantly changing efficient mineral separations become difficult. Kaolinized parts of the alaskite mass are particularly difficult to handle because the clay particles impede the action of the flotation reagents. Biotite can be separated, but other iron-bearing minerals, especially tourmaline and limonite, are hard to remove.

Sheet mica

Although much sheet mica was mined in the district at subsidy prices during World War II, production had fallen from the war peak at the time of the mapping in 1949 and 1950. Considerable reserves of sheet mica exist in the district, but subsidized prices are required before it can be mined. No sheet mica is produced from milling operations.

Scrap mica

Scrap mica is in steadily increasing demand. Small quantities are saved as a by-product of mining in the large feldspar pegmatites, but most of the scrap mica comes from three other sources: (1) the alaskite flotation plants, (2) the hydraulic mining of thoroughly weathered alaskite or pegmatite, (3) recovery as a by-product from the kaolin processing plants. The quantity of scrap obtainable from either of the last two sources is distinctly limited, but the huge quantities of fresh alaskite available for flotation also provide a great source of scrap mica. Under present economic conditions, however, mica is a by-product and the rock is mined primarily for feldspar.

Garnet

Garnet can be successfully separated by the flotation process. This garnet is not the best grade for abrasive uses, because it generally is fractured or marked by incipient fractures at the time it is mined. At present its economic value is negligible.

Quartz

The quartz separated by the flotation process is usually low in iron, more so than the cleanest sandstone quartz mined, so that it is finding an increasing market in the optical industry.

Accessory minerals

The rare-earth, uranium, tantalum, columbium, and beryllium minerals which occur in the pegmatites are relatively rare and are not a major product.

Kaolinite and halloysite

There are two types of commercial clay minerals in the district, kaolinite and halloysite. The latter forms only a small part of the clay resources.

The kaolinite deposits are residually derived from the weathering of alaskite masses. They contain kaolinite mixed with partially altered oligoclase and perthitic microcline with essentially unaltered quartz and muscovite. All commercial bodies underlie older terrace levels of the North and South Toe Rivers and their tributaries. Extensive decomposition during an earlier, incomplete erosion cycle seems to have caused the kaolinization. The depth of thorough kaolinziation ranges from 40 to 100 feet in the commercial deposits. The low iron content, generally under 1 percent for the washed clay, makes possible the production of a white kaolin of uniformly high grade. The washed clay is composed of kaolinite, minor halloysite, as well as some quartz and fine mica which escaped the separation process.

Although all of the weathered alaskite bodies contain some halloysite, it is only in weathered perthite zones of pegmatite that the halloysite is dominant over kaolinite and could be mined as a special product.

Dunite, soapstone, and associated minerals

Three sizeable ultramafic bodies were mapped in the Plumtree area; two of which might yield commercial dunite and the other soapstone. These bodies are located near Frank, near the head of Henson Creek, and along Soapstone Branch.

The Frank deposit, which has been studied by Hunter and Rankin (1941), lies along the North Toe River just south of U. S. route 19E in the northeast corner of the area. This well-exposed and well-zoned body is 1,400 feet wide. The fringe zone contains anthophyllite asbestos, foliated green talc, and vermiculite. The intermediate zone consists of partially serpentinized dunite. The core consisting of relatively unaltered granular olivine is split into two parts.

The dunite body 800 by 300 feet in the Henson Creek valley is largely surrounded by hornblende gneiss. The border zone of fibrous asbestos (up to 2 inches in length) and talc is well exposed on the northwest edge of the body. The central magnesian olivine core contains an estimated 2 to 3 percent chromite and magnetite. Scattered veins of serpentine and talc cut the olivine. There is chloritic soapstone along the northwest edge of the body between the border zone and the country rock.

The deposit 600 feet long up Soapstone Branch is entirely altered to soapstone which has developed more schistosity than other dunite bodies. The contact and the lineation of the prismatic crystals strike north with a steep dip. The western border of talc, actinolite, and chlorite is 2 to 3 feet thick. The next 7 feet consists of high grade talc clusters. The interior is hard rock consisting of an amphibole aggregate with some talc. The outer parts of this body could be used for soapstone, but the interior is much too hard.

The vermiculite associated with these ultramafic bodies is generally of good quality and has economic value. Some vermiculite has been produced from the Frank deposit, but bodies in other parts of the district, like the Day Book dunite deposit 6 miles north of Burnsville, have produced greater tonnage. The probable amounts of recoverable vermiculite in the dunite bodies of the Plumtree area would not warrant mining operations for this commodity alone. Because of the origin of the vermiculite from the weathering of phlogopite, the reserves of the former are limited to the depth of the zone of weathering.

The talc of these bodies is of good quality and has commercial value, but the high costs of transportation to a distant market make it impractical to develop these deposits.

Although some anthophyllite asbestos has been produced in the area, the material is low grade because the average 2 to 3 inch long fibers are too short for most commercial uses.

Table 9.--List of the major mines in the Plumtree area

1. Lock Log*
2. Bluff
3. Elk
4. Field
5. "A"
6. Emmons Knob
7. White Rock
8. Plumtree
9. Pinstock
10. Fall Branch
11. Slippery Elm
12. Freel Vance
13. Johnson
14. Benfield
15. Hoppey
16. Chestnut Mountain
17. Woody
18. Matilda Vance
19. Buck Hill
20. Big Meadow
21. Tom Carpenter
22. Red
23. Pancake
24. Pine Branch
25. Grapevine
26. Honey Waits
27. Wiseman
28. Hempile
29. Waterhole
30. Patrick
31. Gusher Knob kaolin mines
32. Mullins (near High Knob)
33. Horton Rock
34. Ed Buchanan
35. Branch
36. Gimble
37. Bartlet
38. Dave Green
39. Cloudland
40. Ben Cox
41. Milt Wilson
42. Buckeye
43. Adam Buchanan
44. Barrett
45. Alfred
46. Doublehead
47. Houston Rock
48. Bug Rock
49. Charlies Ridge
50. Justis
51. Aldrich
52. Branch (in little Henson Creek)
53. Boonfield
54. Champ Rock
55. Wolf Ridge
56. Pitman
57. Bergen Rock
58. Carter Buchanan
59. Hawk
60. Joe Stevenson
61. Mary Green
62. Pres. Buchanan
63. Bardon
64. Charley Stamey
65. Clarissa
66. Mossy Rock
67. Haw Flat
68. Little Hawk
69. Dobie and Russ Buchanan
70. Bozo
71. Hawk Ruby
72. Little Hawk in Henson Creek
73. Dugger
74. Birch
75. Happy Hill
76. Landers
77. Old Black or Vance Black
78. Connahey
79. Shop
80. Powdermill
81. Four Foot Square
82. Charley Burleson
83. Bad Branch
84. Meadow
85. Marie
86. Lincoln Rock
87. Black
88. Puncheon Camp
89. Dover Bailey
90. Beech Bottom

*Numbers refer to those used with mine symbols on plate 1.

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