COMMONWEALTH OF VIRGINIA

DEPARTMENT OF CONSERVATION
AND ECONOMIC DEVELOPMENT

DIVISION OF MINERAL RESOURCES

GEOLOGY AND MINERAL RESOURCES OF GREENE AND MADISON COUNTIES

Rhesa M. Allen, Jr.

BULLETIN 78

VIRGINIA DIVISION OF MINERAL RESOURCES

James L. Calver
Commissioner of Mineral Resources and State Geologist

CHARLOTTESVILLE, VIRGINIA
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Commonwealth of Virginia
Department of Purchases and Supply
Richmond
1963

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GEOLOGY AND MINERAL RESOURCES OF GREENE AND MADISON COUNTIES

By

RHESA M. ALLEN, JR.

ABSTRACT

Greene and Madison counties are in north central Virginia and are located in the Blue Ridge and Piedmont physiographic provinces. Their boundaries enclose an area of 470 square miles which extends from the crest of the Blue Ridge Mountains in the northwest to Orange County on the southeast.

Bedrock of the counties consists predominantly of Precambrian to early Cambrian igneous and metamorphosed sedimentary and igneous rocks. A small exposure of Lower Cambrian sedimentary rocks is in the extreme southwest corner of Greene County. Triassic sedimentary and igneous rocks occur in eastern Madison County. Quaternary alluvial deposits are in the lower valleys of the major streams of the area. The oldest Precambrian formations consist of gneissic and granitoid rocks of the Virginia Blue Ridge complex which are overlain in part by metamorphosed sedimentary rocks of a schistose, phyllitic and quartzitic nature. The Catoctin formation overlies conformably the metamorphosed sedimentary rocks of the Swift Run formation and overlies unconformably the rocks of the Virginia Blue Ridge complex. In southwestern Greene County the Loudoun and Weverton formations of the Lower Cambrian appear to unconformably overlie the Catoctin formation.

The Virginia Blue Ridge complex forms the core of the Blue Ridge-Catoctin Mountain anticlinorium. In the Greene-Madison area it consists of a series of gneissic and granitoid rocks that grade from the Pedlar formation on the northwest through Old Rag granite, Lovingston formation and Marshall formation to the Robertson River formation on the southeast. Age relations of the rocks of the complex have not been definitely established, although in this area the Lovingston formation appears to be the oldest core unit and the Robertson River formation the youngest. From west to east, unconformably overlying the rocks of the complex are the Swift Run formation, the Mechum River formation, and the Lynchburg formation. Amphibolites and ultramafic bodies, either of volcanic, plutonic, or metasomatic origin, are abundant

in the Lynchburg formation, and small amphibolite masses occur in the rocks of the complex. The Catoctin formation, essentially altered basaltic flows and pyroclastic material, is exposed on the crest and southeast flank of the Blue Ridge and on the extreme east edge of Madison County along the Rapidan River. In eastern Madison County, Triassic sedimentary and altered igneous rocks are in fault contact along their west border with the Lynchburg formation. The east margin of the Triassic is in fault contact with Catoctin formation.

The major structure of the Greene-Madison area consists of the broad upwarp of the Blue Ridge-Catoctin Mountain anticlinorium. Gravity faults displace rocks of the complex and Catoctin formation along northeasterly and northwesterly trends. Minor strike-slip faults, small thrust faults, and shear zones are also present in the rocks of the complex and the Lynchburg formation. The northeastward-trending Mechum River formation appears to represent a downfaulted, and later thrust-faulted, wedge in the Lovingston formation. Thoroughfare Mountain is a synclinal complex composed of a coarse clastic facies of the Lynchburg formation. A series of northeastward-trending gravity faults, offset by northwestward-trending transverse faults, are present along the west margin of the Triassic area.

The mineral resources of Greene and Madison counties consist in part of gneissic and granitic rock along with sand and gravel for construction uses, unakite (a facies of the Pedlar formation) for use as a gem stone, and an ultramafic "soapstone-like" rock which may have potential value. The copper ores of the Blue Ridge have been worked in the past but appear to be of poor quality and limited quantity, and it is doubtful that they will receive attention in the future. Small amounts of pyrite occur at several places in the area. Clays are present, especially in association with Triassic sediments. Titanium-bearing minerals, especially ilmenite and sphene, occur in greater than normal quantity in the Lovingston formation and Robertson River formation north of Madison. Surface water is plentiful but developed sources of ground water have sometimes been in short supply.

INTRODUCTION

LOCATION OF THE AREA

Greene and Madison counties are in the north central part of Virginia (Figure 1), having their western boundaries along the crest of the Blue Ridge and lying chiefly within what is generally known as the Inner Piedmont physiographic province. Counties bordering Greene

and Madison on the north are Page and Rappahannock; on the east and southeast, Culpeper and Orange; on the south, Albemarle; and on the west, Rockingham. The counties lie between lines of longitude 78°05′ and 78°40′ W. and lines of latitude 38°11′ and 38°37′ N. and are shown on eight 15-minute quadrangle maps: Charlottesville, Elkton, Madison, Rapidan, Sperryville, Stoney Man, Gordonsville, and University.

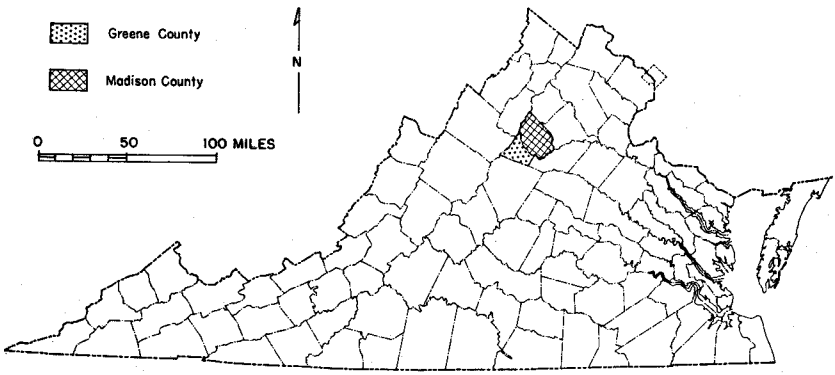


Figure 1. Index map showing location of Greene and Madison counties.

PURPOSE AND SCOPE

The primary purpose of this report is to serve as a guide to the geology of Greene and Madison counties and to present for the first time a geologic map of the major rock units. Previous publications have noted some of the rocks that crop out within the counties, and have reported in detail on small areas within the counties, emphasizing specific topics. This report establishes, using a modern topographic base, the major structural relations, the geologic history and geomorphology of the area, and outlines the mineral resources of present and future interest.

PREVIOUS INVESTIGATIONS

The Geologic Map of Virginia (1911) and its revision (1916) show Precambrian diabase making up the crest of the Blue Ridge along the west margin of the counties, and along the valley of the Rapidan River in the eastern part of Madison. Precambrian granite and granite gneiss are mapped over a broad area through the central part of the counties, and the east margin of the two counties is mapped as Cambrian. Phalen (1906) and Weed (1911) reported on the copper occur-

rences of the Blue Ridge near Elkton and Luray. Keith (1894) published the first comprehensive report on the Catoctin, although the area he described is in Rappahannock, Warren, Fauquier, and Loudoun counties, Virginia.

The broad reconnaissance studies of A. I. Jonas (1927) were incorporated in the Geologic Map of Virginia (1928). Further work by Jonas (1929, 1935), Jonas and Stose (1939), and Stose and Stose (1946) outlined the framework of the regional geology for a large area in the Piedmont and Blue Ridge. Furcron (1934) described several of the igneous rock types in the Shenandoah National Park area. The Triassic rocks along the east margin of Madison County were described by Roberts (1928).

Of a more recent nature are the works of King (1949) on the base of the Cambrian and his (King, 1950) detailed map of the Elkton, Virginia area; Brown (1953, 1958) on the Virginia Piedmont; Caliga (1948) on the geology of the Ruckersville, Virginia area; Reed (1955) on the Catoctin near Luray, Virginia; Gooch (1958) on the metasedimentary rocks in Greene and Madison counties; Brophy (1960) on copper mineralization in the Catoctin; and Brent (1960) on the geology of Rockingham County, Virginia. Studies by Bloomer and Bloomer (1947), Bloomer and Werner (1955), and Bloomer (1955) in the Piedmont and Blue Ridge of central Virginia have contributed to the geologic knowledge of this general part of the State. Nelson (1962) described the geology and mineral resources of Albemarle County that borders Greene County to the south. The above publications either are general in their treatment of Greene and Madison counties, touch on the borders of the counties, or are concerned with specific or local areas. Some of these publications have been utilized in the preparation of this report.

PRESENT INVESTIGATIONS

In the preparation of the geologic map of Rockingham County (Brent, 1960), the mapping of the geology of the Blue Ridge in the eastern part of Rockingham, by the writer, extended the work of King (1950) to the east and south to the border of Greene County. Greene and Madison counties were mapped during the summers of 1958, 1959, 1960, and 1961, at which times the writer was in the employ of the Virginia Division of Mineral Resources. The mapping utilized aerial photographs and enlarged sheets of the 15-minute topographic quadrangles. Advance sheets of the Rapidan, Sperryville, and Trevilians (Gordonsville) quadrangles (scale 1:24,000) were used to supplement aerial photographs for the eastern part of Madison County. Along with

mapping of surface exposures, examinations were made of mineral deposits of economic or potentially economic value and those deposits that have been of interest in the past.

The perplexing problem of the lower boundary of the Cambrian in the rocks that underlie the Blue Ridge and Piedmont physiographic provinces was considered, and field data are presented that may help solve it. The nature and location of the west margin of the Triassic rocks in the mapped area were determined, and the age and relationships of the greenstones associated with the Precambrian-Triassic contact were outlined.

ACKNOWLEDGMENTS

The writer is indebted to Dr. James L. Calver, Commissioner of Mineral Resources and State Geologist of Virginia, for assistance of many kinds in the conduction of the field work. Dr. E. O. Gooch, formerly with the Virginia Division of Mineral Resources, visited the writer in the field during 1958 and 1959 and contributed many helpful suggestions. Dr. Hatten S. Yoder, Jr. of the Carnegie Geophysical Laboratory, Washington, D. C. contributed much valuable information on mineral identifications of several rock types.

Numerous persons in Greene and Madison counties, especially county officials and the county agricultural agents, and officials of the National Park Service were most cooperative and helpful. In particular, the aid of Mr. John Elder, Soil Scientist of the U.S.D.A. team in Madison County, in directing the writer's attention to several interesting geologic features is appreciated. The aid and courtesies, and the genuine interest shown to the writer by the residents of the area are highly appreciated, and it is unfortunate that space does not permit the listing of their individual contributions.

Without the help of field assistants, Benton Long in the summer of 1958, Carlisle Spiker in the summer of 1959, Robert Holder in the summer of 1960, and Merrick Whitfield in the summer of 1961, the field work would not have progressed efficiently; to these men the writer is especially grateful for their assistance.

GEOGRAPHY

CLIMATE

Climatic conditions of the area are summarized from the climatographic data published by the Weather Bureau (Rice, 1959). For the period 1931-1952 the mean maximum temperature for January was

42°F along the crest of the Blue Ridge and 47°F at the lower elevations, and the mean minimum temperature for January was 23°F in the Blue Ridge and 27°F at the lowlands. The mean maximum temperature for July was 79°F along the crest of the Blue Ridge and 84°F at the lower elevations, and the mean minimum temperature for July was 58°F in the Blue Ridge and 64°F at the lower elevations. Also, for the period 1931-1955 the mean annual precipitation was 48 inches in the higher elevations along the crest of the Blue Ridge and 44 inches at the lower elevations along U. S. Highway 29.

Mean temperature and precipitation data from the Weather Bureau stations at Charlottesville, Albemarle County, and Culpeper, Culpeper County, for the period 1931-1955 indicate the climatic picture for the major part of Greene and Madison counties:

Averages for the period:	Charlottesville Temp. (°F.)	Precipitation (inches)	Culpeper Temp. (°F.)	Precipitation (inches)
January	37.5	3.48	37.2	3.20
February	38.5	2.64	37.9	2.37
March	45.9	4.00	46.1	3.42
April	56.3	3.71	55.7	3.68
May	66.4	4.03	65.6	4.27
June	73.9	4.13	73.4	3.69
July	77.3	5.55	77.0	4.77
August	75.9	4.85	75.0	4.48
September	69.9	4.11	69.0	3.53
October	59.8	3.29	58.4	3.08
November	48.2	3.13	46.9	3.17
December	38.5	3.57	37.3	2.94
Annual	57.3	46.49	56.6	42.60

The freeze data from the Charlottesville and Culpeper stations during the period 1921-1950 indicate for Charlottesville the mean date of the last spring freeze is April 11, and the mean date of the first fall freeze is November 6; the average number of days between dates is 210. For Culpeper, the mean date of the last spring freeze is April 21 and the mean date of the first fall freeze is October 22; the average number of days between dates is 184. Although this part of Virginia is normally favored with abundant rainfall, the frequency of dry spells and droughts greatly affects agricultural activity. The drought of 1930 is thought to have been the most serious of the past century.

TOPOGRAPHY AND DRAINAGE

The counties of Greene (area—153 square miles) and Madison (area—327 square miles) lie within the Inner Piedmont and Blue Ridge physiographic provinces (Fenneman, 1938, pp. 139-140 and

pp. 165-171). The greatest relief is along the west margin of the counties, and the highest point, 4,049 feet, is Hawksbill. Other high elevations in Madison County are Stony Man, 4,010 feet; Old Rag Mountain, 3,291 feet; and Fork Mountain, 3,852 feet. High elevations in Greene County are: Hazletop, 3,816 feet; Hightop, 3,500+ feet; and Flattop, 3,300+ feet.

The lowest elevation of the area is 298 feet at the confluence of Robertson River (shown on some maps as Robinson River) and Rapidan River. The elevation at the town of Madison, county seat of Madison County, is 589 feet, and at the town of Stanardsville, county seat of Greene County, the elevation is approximately 670 feet. The junction of Page-Rappahannock-Madison counties has an elevation of 3,334 feet; the junction of Page-Madison-Green counties, 3,530 feet; and the junction of Greene-Albemarle-Rockingham counties, 3,010 feet.

The area is drained by Hughes River; Robertson River, a major tributary of the Rapidan River; Rose River, a tributary of Robertson River; Conway River that drains into Rapidan River; South River, a tributary to the Rapidan; and Roach and Lynch rivers that drain into the North Fork of the Rivanna River.

Records of the quantity of water discharged by Rapidan River and Robertson River indicate the extreme fluctuation of these streams. The following data are from the U. S. Geological Survey (Surface Water Supply Paper 1,622, 1959, pp. 493-495):

Rapidan River at the crossing of U. S. Highway 29.

Drainage area—111 square miles
Record for the period September 1942-September 1959
Average discharge over 17 years—153 c. f. s.
Maximum of 30,700 c. f. s. on October 15, 1942
Minimum of 3.8 c. f. s. on September 4-5, and October 1-5, 1953

Robertson River at the crossing of State Road 614 near Locust Dale.

Drainage area—180 square miles
Record for the period July 1943-September 1959
Average discharge over 16 years—209 c. f. s.
Maximum of 18,600 c. f. s. on August 18, 1955
Minimum of 1.2 c. f. s. on September 7 and 13, 1954

Rapidan River at the bridge on U. S. Highway 522, six miles downstream from Madison County.

Drainage area—465 square miles
Record for the period November 1930-September 1959
Average discharge over 29 years—519 c. f. s.
Maximum of 58,101 c. f. s. on October 16, 1942
Minimum of 2.1 c. f. s. on October 4-5 and 11, 1954

Topography in the western portion of the counties includes steep-walled valleys with fast-flowing streams and heavily wooded slopes and in the eastern portion a gently rolling surface of the Piedmont. Along the Rapidan and other major streams are flat flood-plain surfaces with locally developed terraces. At scattered intervals on the rolling surface of the Piedmont are low hills that represent erosional remnants of a former eastward extension of the Blue Ridge highlands. Gaar Mountain and Thoroughfare Mountain in Madison County and Parker Mountain and Bingham Mountain in Greene County are but four of numerous occurrences of outliers of the main Blue Ridge upland. The greater part of the rolling Piedmont surface is wooded or covered by pasture, and the larger cultivated tracts are in the valleys of major streams.

INDUSTRY AND ECONOMIC DEVELOPMENT

The 1960 census recorded a population of 8,187 persons in Madison County for a density ratio of approximately 25 persons per square mile and 4,715 in Greene County for a ratio of about 31 persons per square mile. Each county has had a loss in population since 1930. For the period 1957-1959 the per capita income for Madison County was $905 annually and for Greene County $887, compared with the State average of $1,670.

At the time of the field investigation there were no mining or quarrying activities in either of the counties, although in the past granitic rock has been quarried for road metal, and several mines were opened in the Blue Ridge for copper ores. In Greene and Madison counties, farms average about 150 acres, and the greatest percentage of them are under 50 acres. In the western part of the counties are extensive orchards of apples and peaches. Livestock and poultry raising are the dominant forms of agriculture on the foothills of the Blue Ridge and the rolling Piedmont slope. Along the river flood plains and terraces, hay and grain crops are produced.

Madison County contains approximately 87,352 acres of commercial, and 32,400 acres of non-commercial forest area, and Greene County

contains about 48,397 acres of commercial and 13,800 acres of non-commercial forest area. The non-commercial acreage is within the boundaries of the Shenandoah National Park. There is one bank in Stanardsville and one in Madison. Along the Rapidan River in the southeastern part of Madison County is the Woodberry Forest School, a preparatory school for boys.

TRANSPORTATION FACILITIES

The closest railroad to Greene and Madison counties is the Southern Railway which passes through Barboursville and Orange, Orange County, a few miles to the east. A small airfield has been maintained at Syria in Madison County on the Robertson River. Excellent commercial airport facilities are available at Charlottesville, Albemarle County, some 27 miles south of Madison.

The area is served by a network of good roads. U. S. Highway 29 passes northward through Ruckersville and Brightwood, and U. S. Highway 15 passes through Madison Mills and Locust Dale. From Gordonsville, Orange County, westward, U. S. Highway 33 passes through Ruckersville where it crosses U. S. Highway 29, and continues westward through Stanardsville and crosses the Skyline Drive on the crest of the Blue Ridge at Swift Run Gap. The Skyline Drive follows the Blue Ridge crest along the west margin of the two counties. Many hard-surfaced State roads give easy access to the central and eastern parts of the counties, but in the western area adjacent to the Shenandoah National Park, roads are few and not suitable for travel in bad weather.

ROCKS OF THE AREA

The rocks of the area are mainly igneous and metamorphosed igneous and sedimentary types. Lower Cambrian sedimentary types occur along the crest of the Blue Ridge, and Triassic types are present in the eastern part of Madison County. Also, portions of the Swift Run formation appear to be of sedimentary origin. From west to east major units are: 1) the lowermost Cambrian units noted as the Weverton and the underlying Loudoun formations which appear to lie unconformably on the Catoctin formation of early Cambrian or late Precambrian age; 2) the igneous and metamorphic complex generally known as the Blue Ridge-Catoctin Mountain anticlinorium by virtue of its spatial relationships with rock units to the east and west; 3) a syncline of schistose and gneissic rocks grouped under the heading of Lynchburg

formation along with associated dike- and sill-like bodies; and 4) the downfaulted Triassic sedimentary rocks and igneous masses that occur along the east margin of Madison County.

The Weverton, Loudoun, and Catoctin formations form the west flank of the Blue Ridge-Catoctin Mountain anticlinorium and in general have the appearance of a corrugated plate with a westward tilt that makes up the west slope of the Blue Ridge in this area. Between the Catoctin formation and the underlying igneous and metamorphic complex is a heterogeneous mixture of rock types known as the Swift Run formation. The complex of gneissic, schistose, granitoid and migmatitic rocks, that comprise the main mass of the Blue Ridge-Catoctin Mountain anticlinorium and underlie the east flank of the Blue Ridge and the upland surface of much of the two-county area, is herein referred to collectively as the Virginia Blue Ridge complex. Trending northeastward in the central portion of the two counties is a faulted and infolded mass of schistose rocks known as the Mechum River formation. Unconformably overlying the Virginia Blue Ridge complex, the Lynchburg formation extends eastward from near U. S. Highway 29 to where it is in fault contact with Triassic rocks near the Rapidan River. Dike- and sill-like amphibolites and ultramafic bodies are within the Lynchburg formation and the Virginia Blue Ridge complex. Triassic sedimentary rocks and igneous masses are present only along the easternmost margin of Madison County. Geologic formations of Greene and Madison counties are illustrated in Figure 2.

PRECAMBRIAN ROCKS

The Virginia Blue Ridge complex was named by Brown (1958, p. 7) as a geographical name to be applied to those rocks previously called "injection complex" (Jonas and Stose, 1939), "granitized complex" (Bloomer, 1950), and "basement complex" (Bloomer and Werner, 1955). In this report the name Virginia Blue Ridge complex and the term "basement" will be used interchangeably to identify the schistose, gneissic, granitoid, and migmatitic rocks that are older than the Swift Run, Mechum River, and Lynchburg formations.

The rock units of the Virginia Blue Ridge complex which have been mapped and described in this report are: Lovingston formation, Marshall formation, Old Rag granite, Pedlar formation, and Robertson River formation. A new rock-unit name, Robertson River formation, is suggested for hornblende granite and hornblende syenite masses that generally border the Lynchburg formation on the northwest in Greene and Madison counties. In the mapped area formations in the complex

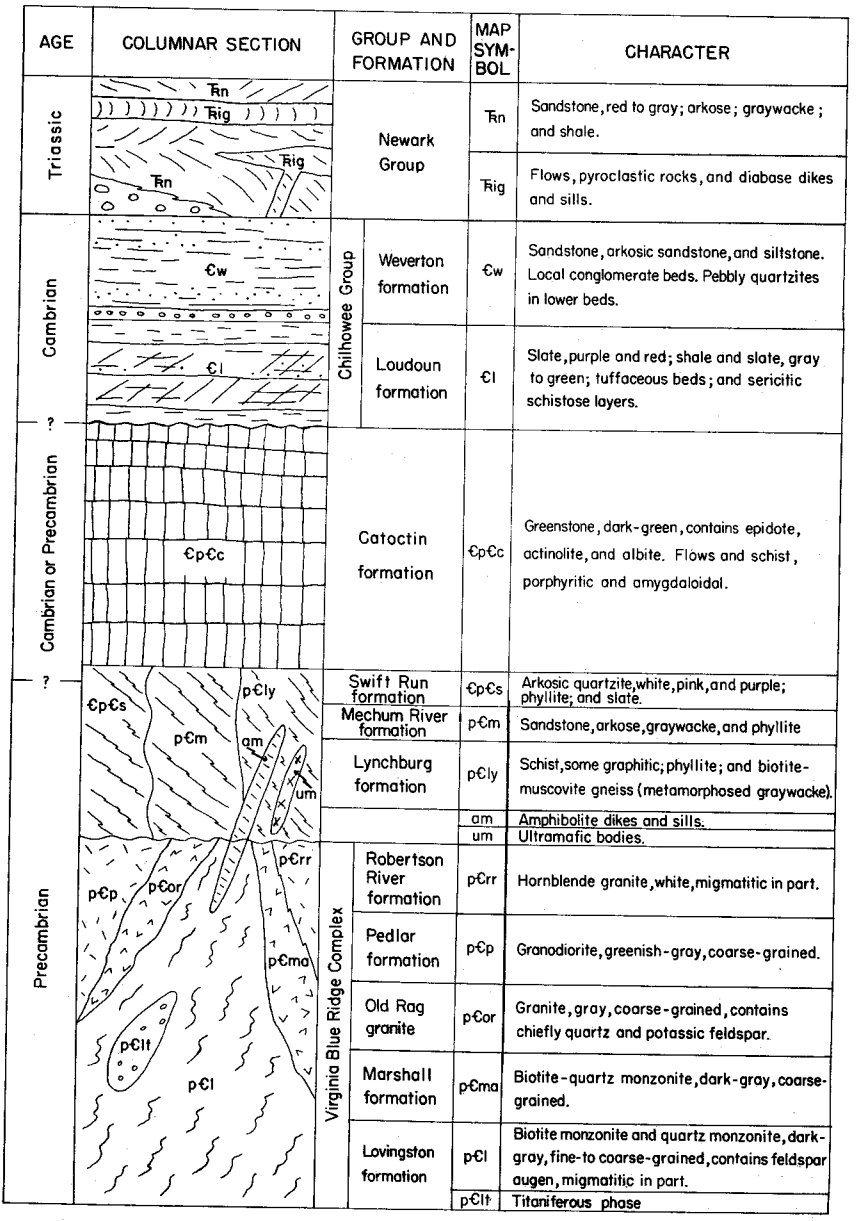


Figure 2. Geologic formations of Greene and Madison counties.

have gradational boundaries; in addition, facies changes occur within the individual rock units. Approximate modes of the rock units of the Virginia Blue Ridge complex are given in Table 1.

Table 1.—Approximate modes of typical specimens of granitoid and gneissic rocks in Greene and Madison counties (in percent).

	Pedlar formation			Lovingston formation					Old Rag granite	Robertson River formation				Marshall formation
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Quartz	17	18	23	26	25	20	10	23	32	20	15	18	2	22
Potassic Feldspar and Perthite	33	31	36	36	50	25	20	22	55	50	48	49	64	35
Plagioclase	36	36	10	28	11	20	24	38	4	15	20	17	12	33
Pyroxene	5	8	3	—	—	—	—	—	—	—	—	—	—	—
Amphibole	3	—	X	—	—	—	—	—	3	10	2	12	15	3
Biotite	1	2	2	7	5	16	25	7	1	2	2	—	3	5
Muscovite	2	—	—	2	3	—	X	2	—	—	2	—	X	X
Chlorite	2	X	3	—	1	3	X	1	—	1	X	—	X	X
Sphene	—	—	—	—	1	3	5	2	1	1	1	1	1	X
Garnet	—	—	—	—	—	5	10	1	—	—	2	1	1	1
Apatite	—	1	X	X	1	1	2	1	1	X	1	1	1	X
Epidote and Clinozoisite	1	2	23	X	2	1	X	1	2	X	X	X	—	X
Ilmenite	X	2	—	X	1	6	4	2	1	1	7	1	1	1
Leucoxene	X	X	—	X	X	X	X	X	X	X	X	X	X	X

X Present in less than 1 percent.
1. 1 mile southeast of Swift Run Gap on U. S. Highway 33.
2. Millers Head—Skyland.
3. Unakite—Fishers Gap.
4. 0.5 mile west of Mt. Paran Church, Greene County.
5. 1 mile south of Wolftown.
6. End of State Road 695, Madison County.
7. 2 miles north of Madison on State Highway 231.
8. 1 mile east of Syria.
9. Old Rag Mountain.
10. Rapidan River at U. S. Highway 29.
11. 1 mile east of Shelby.
12. 0.5 mile north of Pratts.
13. 3.5 miles north of Madison, State Highway 231.
14. 1 mile north of Haywood.

LOVINGSTON FORMATION

Name and Distribution

The broad exposures and the several lithologies of quartz-biotite granite gneisses of the Virginia Blue Ridge complex have been termed variously, but "Lovingston" is commonly used. The Lovingston granite gneiss is named from exposures at Lovingston, Nelson County, Virginia (Jonas, 1928). The rock unit "Lovingston" was retained by Furcron (1935) and by Brown (1953), but Bloomer and Werner (1955) restricted it to the gneissic rock that contained a marked augen development like that at the type locality. Furthermore, Bloomer and Werner (1955) designated the gneissic rock without conspicuous augen, Marshall

formation. The gneissic rock in the vicinity of Marshall, Fauquier County, Virginia, was named Marshall granite by Jonas (1928). Brown (1958) followed the usage of Bloomer and Werner in terming the exposures of gneiss, generally without augen, in the Lynchburg area, Marshall formation.

In exposures of quartz-biotite granite gneiss in the Greene-Madison area, augen development is generally of a pervasive distribution, and the name Lovingston formation is applicable. Exposures (Plate 1), 6 to 8 miles wide, trend northeastward through Greene and Madison counties. Along its west margin the Lovingston grades into the Pedlar formation and Old Rag granite; along its east border, contacts with the Robertson River formation are generally gradational although contacts are somewhat sharper. Within the Lovingston formation are discrete bodies of Old Rag granite and Marshall formation and bodies of mixed gneiss that may be classed as migmatite. Field criterion for identification of Lovingston formation was the presence of augen structure. Where augen structure was not evident, the quartz-biotite granite gneiss was mapped as Marshall formation. Gradual variations within the gneiss necessitated an arbitrary identification of the rock type.

In Greene County excellent exposures of the Lovingston formation occur immediately south of Stanardsville, in the Quinque area, and south of Mt. Paran Church (Figure 3). A broad zone of migmatized Lovingston formation is present to the north and east of Westover Church. In Madison County, good exposures are in the vicinity of Hood and east of Wolftown. A zone of garnetized, titanium-bearing Lovingston formation is well exposed about 2 miles north of Madison. Schistose rocks of the Mechum River formation occur almost wholly within the Lovingston.

Lithology

On fresh exposure, the Lovingston is a greenish-gray, medium-grained gneiss, consisting of quartz, orthoclase and some microcline, plagioclase (generally calcic oligoclase), and brown to olive-green biotite. Layers of feldspar and quartz and feldspar augen are separated by stringers and films of biotite. The gneissic structure is well developed, and only rarely does a non-foliate, or granitoid, variety of Lovingston occur. In these rare instances it is wholly surrounded by the gneissic facies. Microscopic examination shows that plagioclase and potassic feldspar are about equal in quantity, and the rock may be a quartz monzonite gneiss. Much of the plagioclase feldspar is altered and contains small grains of epidote and zoisite. Fresh albite is present as

Figure 3. Photomicrograph of gneiss of the Lovingston formation near Mt. Paran Church along State Road 629, Greene County. Epidotized plagioclase (e-pl), orthoclase (or), fresh albite (al), and biotite (b). Plain light. X 55.

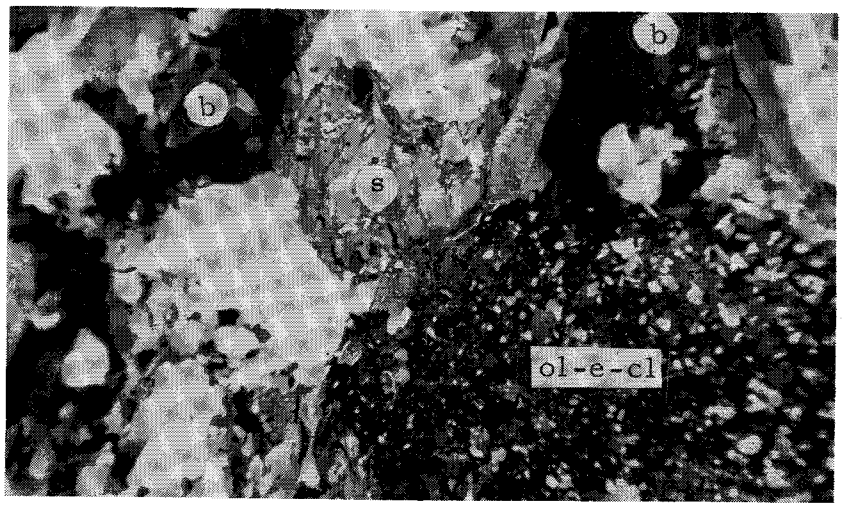
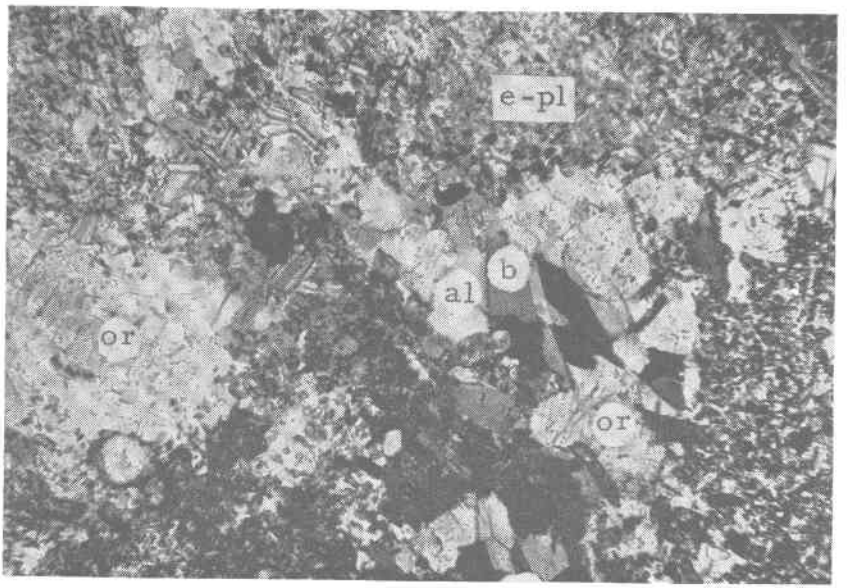


Figure 4. Photomicrograph of titaniferous gneiss of the Lovingston formation along State Road 695, Madison County. Biotite (b), oligoclase with epidote and clinozoisite inclusions (ol-e-cl), and sphene (s). Crossed nicols. X 77.



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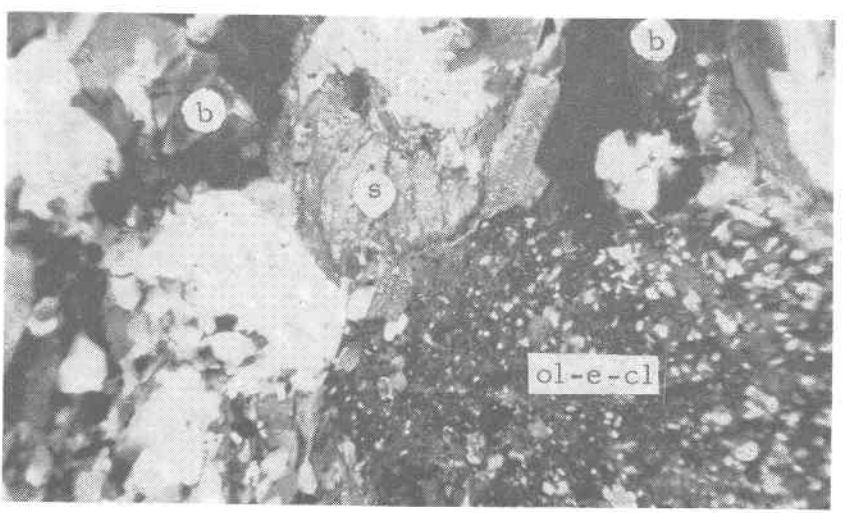

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rims and replacements about altered oligoclase, and small blebs of fresh quartz cut and embay potassic and plagioclase feldspar. Large crystals of fresh epidote, zones of apatite, ilmenite with coronas of sphene and leucoxene (Figures 4, 5), and almandine garnet (Figure 6) are present along zones of shearing.

Shear zones in the Lovingston formation are common, and some of the rock has schistose characteristics along such zones. Border zones of Lovingston in contact with other gneissic and granitoid rocks of the Virginia Blue Ridge complex and schistose rocks of the Mechum River formation contain contorted layers of quartz and feldspar. The rock containing these layers has a migmatitic appearance. Veins of white and blue quartz are common in the Lovingston formation as are grains of blue quartz in the matrix of the gneiss. One such vein of blue quartz, approximately 20 feet in width, can be seen along the bluff above Conway River, southeast of the junction of State Highway 230 and State Road 619.

OLD RAG GRANITE

Name and Distribution

The Old Rag granite was described and named (Furcron, 1934) from rock exposed on Old Rag Mountain, Madison County. In addition to the large exposure making up Old Rag Mountain, the granite extends southwestward from Syria to the vicinity of Graves Mill along the southeast slope of Doubletop Mountain and to the crest of Blakey Ridge. Narrow exposures are present on German Ridge, on Gaar Mountain, on Flattop Ridge and along the southeast slope of Kirtley Mountain. Small masses are present on Neal Mountain, and isolated crops of Old Rag-type granite are present in southern Greene County immediately south of March, and on Sims and Chapman mountains. The Old Rag granite seems to be more resistant to weathering than the other granitoid and gneissic rocks of the Virginia Blue Ridge complex, and for that reason exposures of Old Rag form the higher ridges along the east margin of the Blue Ridge.

The contact between the Old Rag granite and the Pedlar formation is gradational over distances of 1 mile or more. Old Rag-Lovingston contacts are somewhat sharper; the change in lithology between the gneissic texture of the Lovingston and the granitoid texture of the Old Rag develops within a distance of several hundred yards. In the German Ridge and Neal Mountain areas the Old Rag granite is in contact with Mechum River formation. The contact between these

Figure 5. Photomicrograph of titaniferous gneiss of the Lovingston formation along State Highway 231, 2 miles north of Madison. Sphene and replaced garnet (s-g), biotite (b), and perthite (pe). Crossed nicols. X 55.

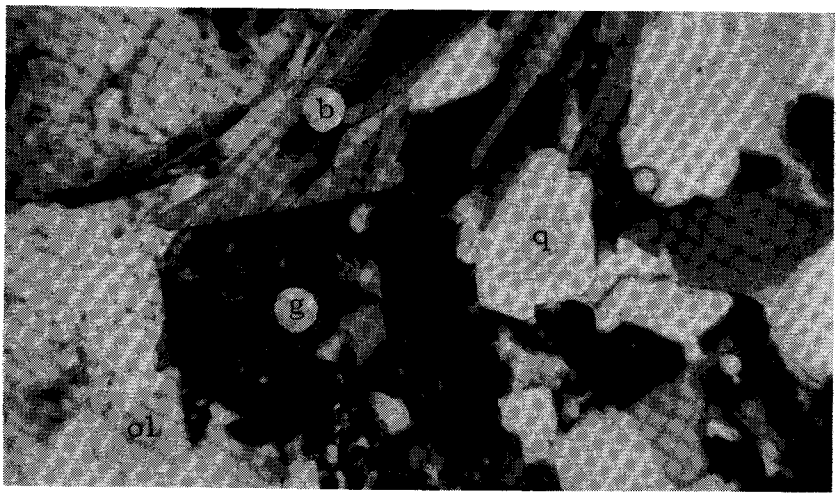


Figure 6. Photomicrograph of gneiss of the Lovingston formation near State Road 695, Madison County. Garnet (g), oligoclase (ol), biotite (b), and quartz (q). Crossed nicols. X 77.

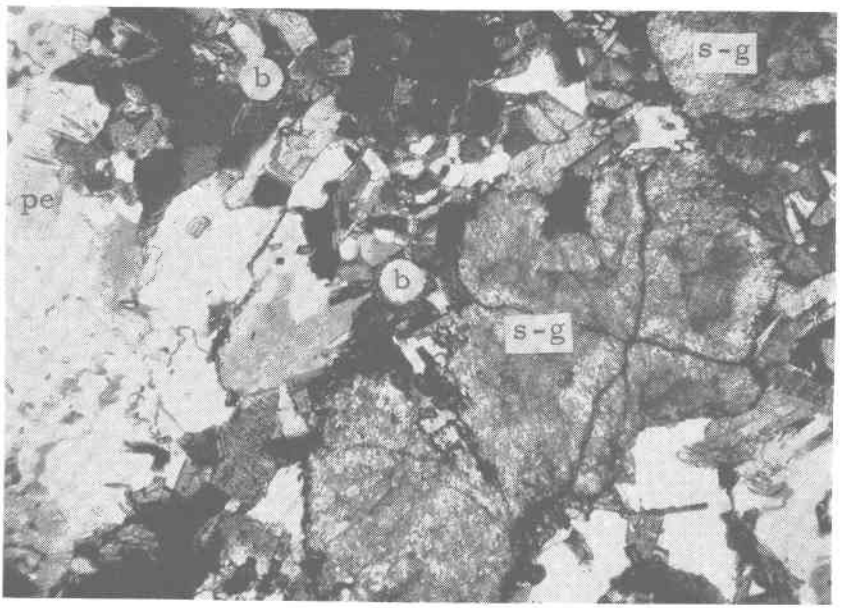


Figure 5. Photomicrograph of titaniferous gneiss of the Lovingston formation along State Highway 231, 2 miles north of Madison. Sphene and replaced garnet (s-g), biotite (b), and perthite (pe). Crossed nicols. X 55.

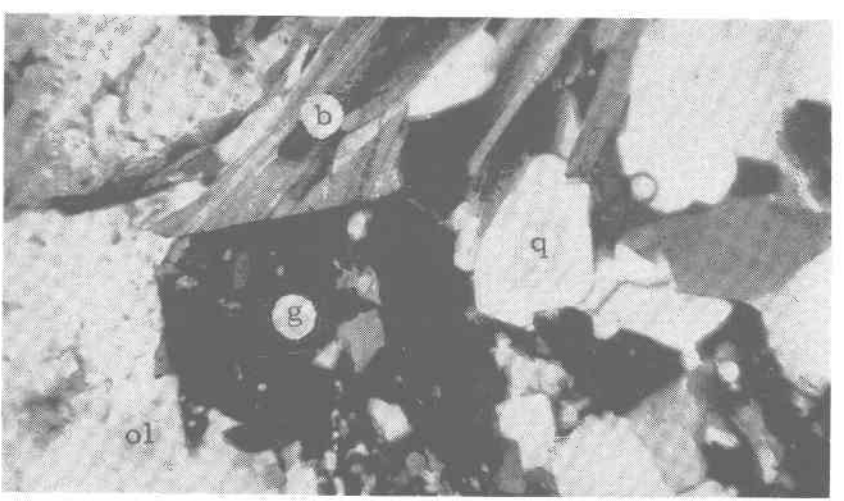


Figure 6. Photomicrograph of gneiss of the Lovingston formation near State Road 695, Madison County. Garnet (g), oligoclase (ol), biotite (b), and quartz (q). Crossed nicols. X 77.

units is in part a fault; the presence of pebbles of Old Rag granite in the Mechum River formation indicates that Mechum River sedimentary material was deposited over the weathered surface of the Old Rag.

Lithology

Old Rag granite has a coarse-grained granitoid texture with individual feldspar crystals (orthoclase or microcline) up to 1.6 inches in length and elongate masses of bluish and smoky quartz up to 0.8 inch. Small quantities of chloritized biotite are present. Microscopically, the orthoclase feldspar is untwinned, and small masses of microcline associated with minute albite rods occur as microperthitic intergrowths. The quartz grains are subhedral, though quartz blebs are common in orthoclase. Epidote is present in small quantities, and scattered grains of green hornblende, apatite, ilmenite, and zircon are present.

On fresh surfaces the Old Rag granite is a grayish milky white, and upon weathering it changes only to a darker gray. A slight foliation is defined by the parallelism of feldspar laths and the intervening bluish or dark-gray quartz stringers. Pits or depressions have been formed in the exposed surfaces of the granite during weathering processes. Many of these depressions are present on the crest of Old Rag Mountain where they have a length of 6 feet, a width of 3 feet, and a depth of 1 foot.

Furcron (1934, p. 406) notes the Old Rag granite resembles a facies of the "Marshall granite" and intrudes the granodiorite. The granite is closely related genetically to granodiorite and is probably a differentiate of the same magma. This granodiorite, the hypersthene granodiorite of Jonas (1935), and the rock described in this report as Pedlar formation, are considered to be identical. The gradational contact of the Old Rag granite with the Pedlar formation indicates the rock units may be closely related.

Several small outcrops of granite in southern Greene County, those in the area south of March, the exposures along Roach River, and those on Sims and Chapman mountains, have been mapped as Old Rag granite. These occurrences, which have pegmatitic textures, may be a local facies of the Lovingston formation.

MARSHALL FORMATION

Name and Distribution

The Marshall granite (Jonas, 1928), named from granitoid and gneissic rocks in the vicinity of Marshall, Fauquier County, Virginia, was used by Bloomer and Werner (1955) to describe gneissic rocks similar to the Lovingston formation but lacking prominent augen.

Brown (1958, p. 11) has followed this definition in the Lynchburg quadrangle. In the Greene and Madison area many of the outcrops of Lovingston lack a "prominent" augen development and arbitrary limits may influence the mapping of these rock types. It may be that areas mapped as Lovingston formation by the writer might be mapped as Marshall formation by other workers. Good exposures of a Marshall-type gneiss are present in the Criglersville-Etlan and Haywood-Novum areas of northeastern Madison County. The contact between the Lovingston and the Marshall formations is gradational for the most part, and the rock types may be minor textural and mineralogic variations of the same rock mass.

Lithology

The Marshall formation on fresh exposure varies from grayish white to greenish white to gray. Gneissic structure appears to be everywhere present and is usually marked by the development of shredded and stretched masses of biotite. Feldspar augen, or eyes, are not prominent in the Marshall; however, an increase in the number and size of augen is evident as the Marshall grades into the Lovingston. Exposures of Marshall contain quartz, feldspar, minor amounts of muscovite, biotite, and chlorite, and scattered grains of ilmenite.

A study of thin sections of Marshall formation, by microscope, indicates the presence of an early quartz in subhedral grains and a later replacement quartz as blebs and microveinlets that cut through early quartz and feldspar. The bulk of the feldspar is orthoclase and a lesser amount of microcline. Much of the potassic feldspar is perthitic, with intergrowths of sodic oligoclase. Anhedral masses of sodic oligoclase are common, and subordinate small anhedral grains of calcic oligoclase and sodic andesine are present in some thin sections of Marshall formation. Biotite is present in all specimens examined; muscovite is present in most samples. The plagioclase feldspars are characterized by small inclusions of epidote. Small grains of ilmenite, apatite, and zircon, and a few small crystals of almandine garnet are present. Coronas of sphene and leucoxene around ilmenite grains are present in the Marshall as well as in the Lovingston formation.

PEDLAR FORMATION

Name and Distribution

Granitoid and slightly gneissic rock of the upland mass of the Blue Ridge consists of many lithologic types including granite, syenite, granodiorite, unakite, and quartz diorite. Bloomer and Werner (1955,

p. 582) suggested the name Pedlar formation for this heterogeneous assemblage. It was indicated chiefly as hypersthene granodiorite (Geologic Map of Virginia, 1928) and was described by Jonas (1935). Bloomer and Werner cited the exposures of granitoid rocks along the upper reaches of Pedlar River in northwestern Amherst County as typical of the formation. There is some advantage in using a name that includes a number of somewhat similar rock types under a single heading, and the term Pedlar formation is used in the Greene-Madison area although the use of the Pedlar some 65 miles to the northeast of the type area introduces some difficulties.

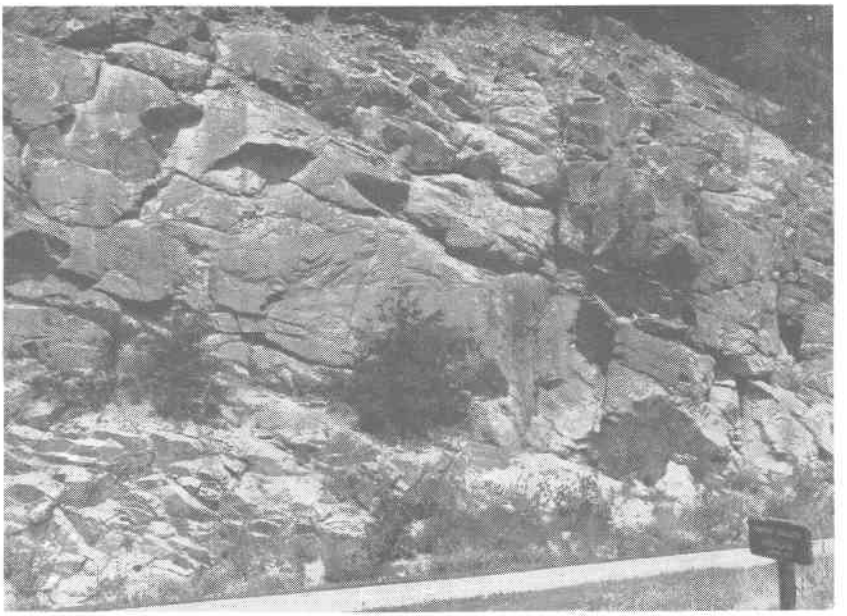
Distribution of the Pedlar formation is shown on Plate 1. Along its west margin, the Swift Run and Catoctin formations are unconformably above the Pedlar, and along the east margin it grades into Old Rag granite and Lovingston formation. The Pedlar formation is about 1 to 3 miles wide in southwestern Greene County and broadens in width to approximately 5 miles in western Madison County. Along the crest of the Blue Ridge for about 5 miles southwest and 2 miles northeast of Swift Run Gap, approximately parallel to the Skyline Drive, the Pedlar formation occurs as a narrow exposure, encircled by the Swift Run and Catoctin formations except for the valley of Swift Run (Figures 7, 8). A small exposure of Pedlar, completely encircled by Catoctin, occurs just south of Fishers Gap on the headwaters of Rose River.

Lithology

Within the outcrop area of the Pedlar formation in Greene and Madison counties, the most prevalent facies is a coarse-textured, dark greenish-gray, quartz monzonite. Fresh exposures are characteristically greenish gray; slightly weathered rock surfaces are light gray to brownish white, and after prolonged exposure the surfaces generally are rusty brown. In some places the Pedlar formation has a poorly to well developed gneissic structure (Figure 9). In hand specimen, feldspar, quartz, and minor quantities of ferromagnesian minerals are evident. The feldspar crystals may be as large as 1 cm; quartz grains are generally smaller. Both a clear quartz and a bluish to purplish-blue quartz are common, and in areas of contact with the Old Rag granite the quartz has a decided gray color. The dark-green color seen on fresh Pedlar exposures is caused by the presence of chlorite. Scattered grains of ilmenite are commonly present. Exposures of unakite are common and several accessible localities are noted in the section on Mineral Resources. Unakite is readily identified by the attractive coloration of pink feldspar, green epidote, and gray to bluish quartz.

Figure 7. Jointed rock in the Pedlar formation at Bacon Hollow Overlook, Skyline Drive.

Figure 8. Contact of Pedlar and Swift Run formations (at figure) along U. S. Highway 33, 0.5 mile west of Swift Run Gap.



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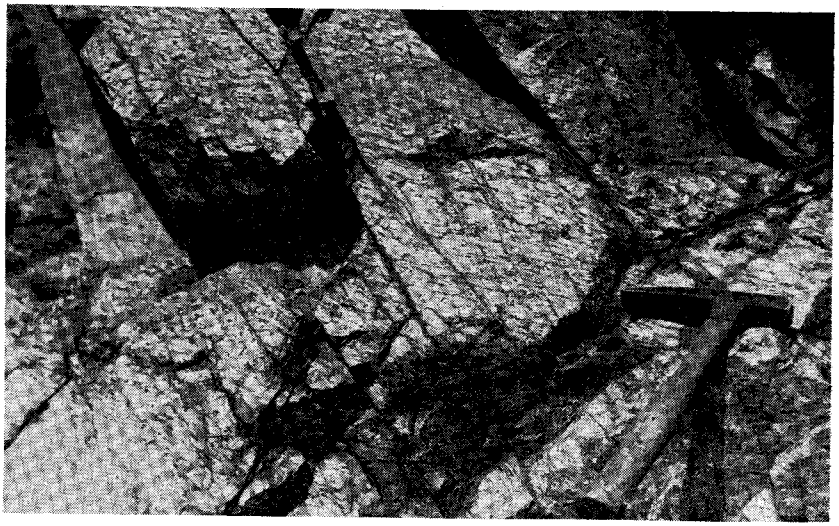


Figure 9. Jointed Pedlar formation showing gneissic structure, Bacon Hollow Overlook, Skyline Drive.

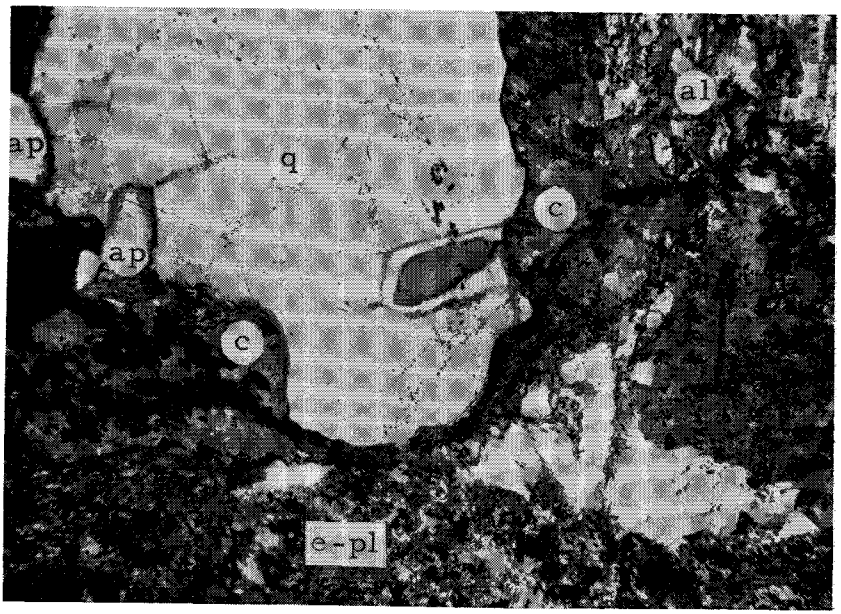
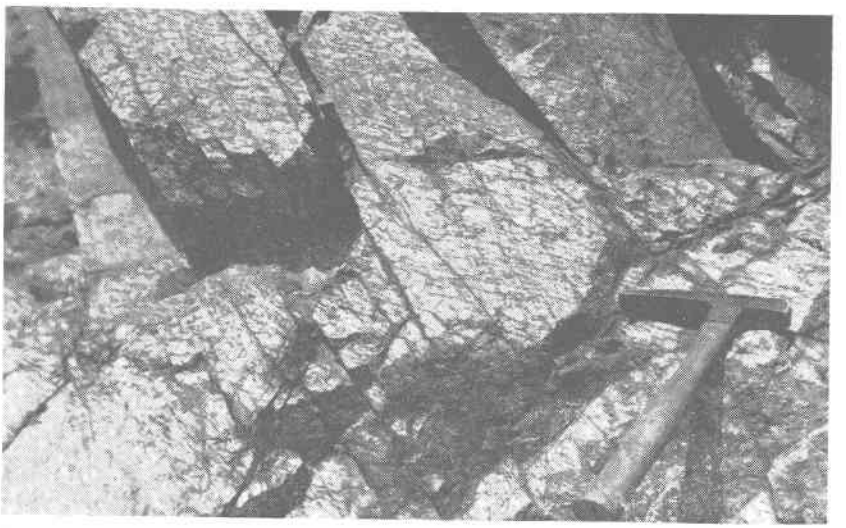


Figure 10. Photomicrograph of granodiorite of the Pedlar formation at cut in U. S. Highway 33, 1 mile south of Swift Run Gap, Greene County. Quartz (q), epidotized plagioclase (e-pl), chlorite (c), replacement albite (al), and apatite (ap). Crossed nicols. X 55.



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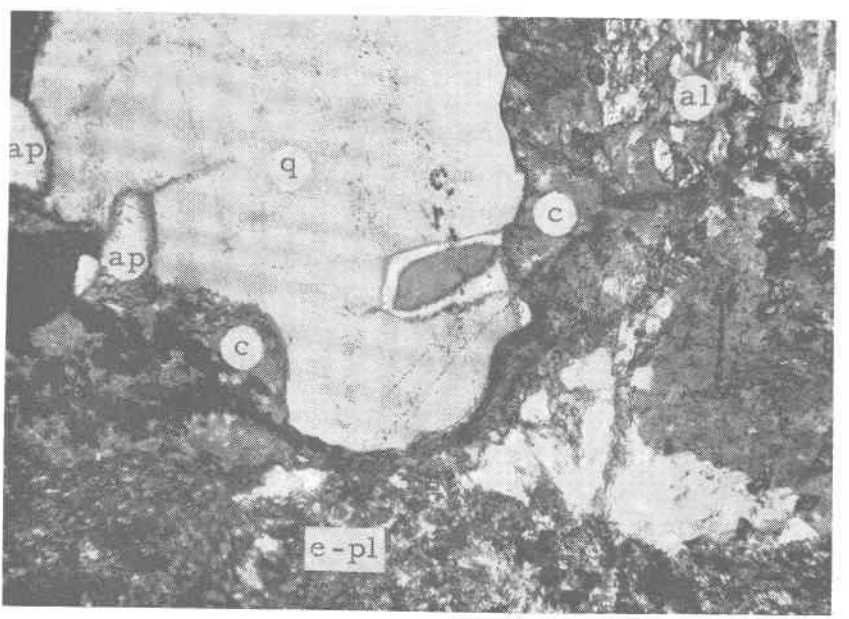

Figure 10. Photomicrograph of granodiorite of the Pedlar formation at cut in U. S. Highway 33, 1 mile south of Swift Run Gap, Greene County. Quartz (q), epidotized plagioclase (e-pl), chlorite (c), replacement albite (al), and apatite (ap). Crossed nicols. X 55.

Petrographic examination of rock specimens from the Pedlar formation indicates it is characterized by a granitoid texture with some foliate structure. Orthoclase, microcline and plagioclase (commonly calcic oligoclase to andesine) make up 60 to 70 percent of the rock; the potassic feldspar and plagioclase occur in approximately equal amounts. Some specimens contain about twice as much plagioclase as potassic feldspar and may be classed as granodiorite or quartz diorite (Figures 10, 11). Much of the potassic feldspar is perthitic. Quartz is always present in amounts ranging from 15 to 25 percent. Hornblende and olive-brown biotite are generally present in amounts of less than 10 percent. Hypersthene and monoclinic pyroxenes occur only as a few scattered grains and are absent in many thin sections. The best development of hypersthene and augite is at Millers Head firetower. Sphene, leucoxene associated with ilmenite, scattered grains of apatite, and a few grains of zircon are common accessory minerals.

Wisps of chlorite between feldspar masses and cloudy areas with small epidote grains in plagioclase are responsible for the gray to green color of most varieties of Pedlar. Replacement is evident by the presence of small blebs and rims of fresh albite associated with the potassic feldspars, myrmekitic intergrowths of albite and oligoclase with quartz, and stringers and veinlets of late quartz penetrating feldspars and older quartz. Field observations indicate that the largest and the best developed masses of unakite occur in the Pedlar just below the cover of Catoctin formation near the unconformity between the formations.

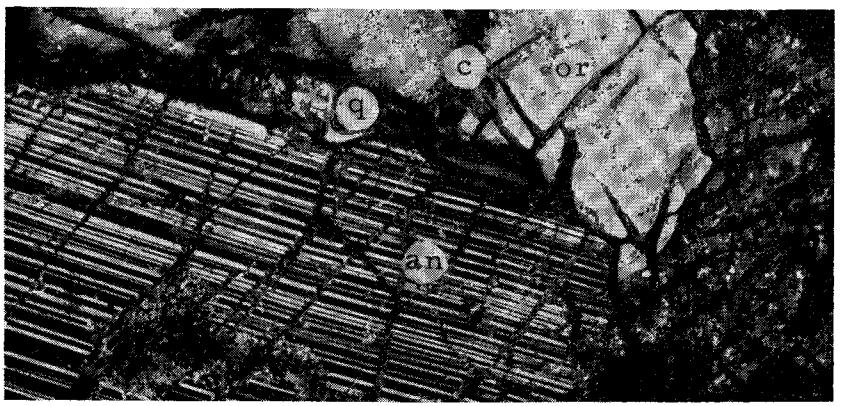

Figure 11. Photomicrograph of granodiorite of the Pedlar formation near Lydia, Greene County. Andesine (an) and orthoclase (or) with chlorite (c) veinlets. Myrmekitic quartz (q) along orthoclase-andesine border. Crossed nicols. X 55.

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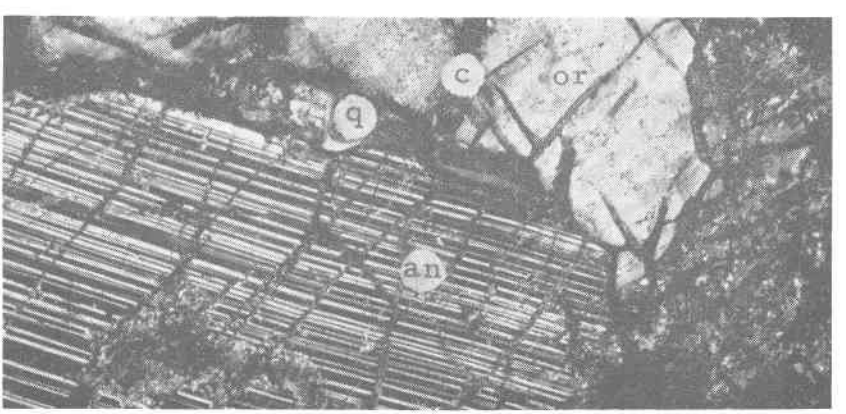

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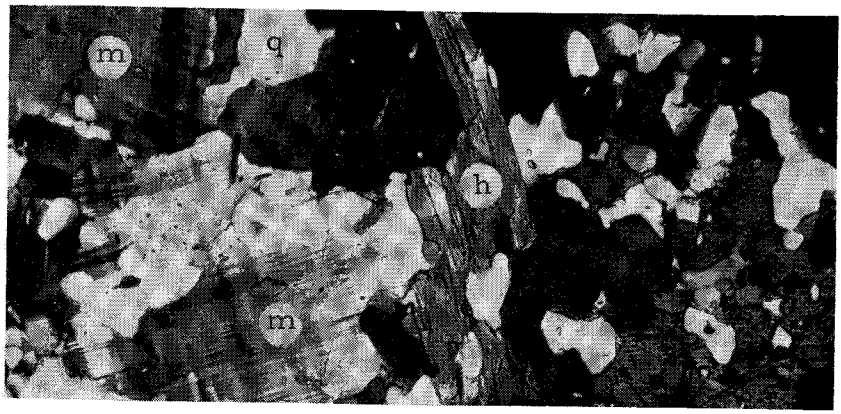

Figure 12. Photomicrograph of granite of the Robertson River formation at cut in U. S. Highway 29 north of Rapidan River, Madison County. Microcline (m), hornblende (h), and quartz (q). Crossed nicols. X 55.

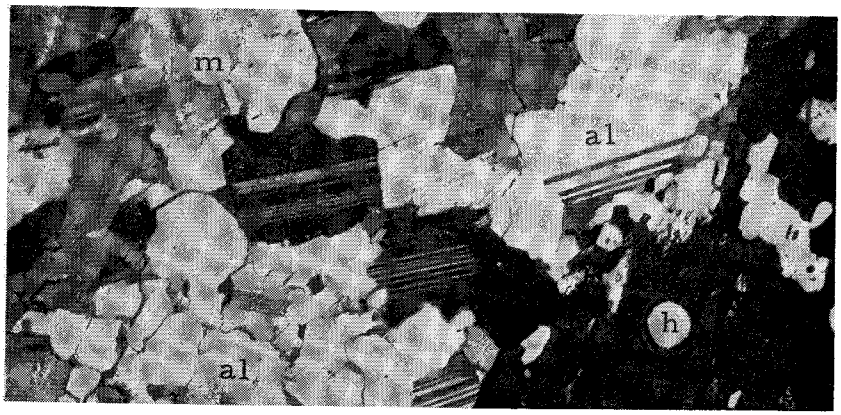

Figure 13. Photomicrograph of granite of the Robertson River formation in quarry west of State Road 687 near Pratts, Madison County. Albite (al), microcline (m), and hornblende (h). Crossed nicols. X 55.

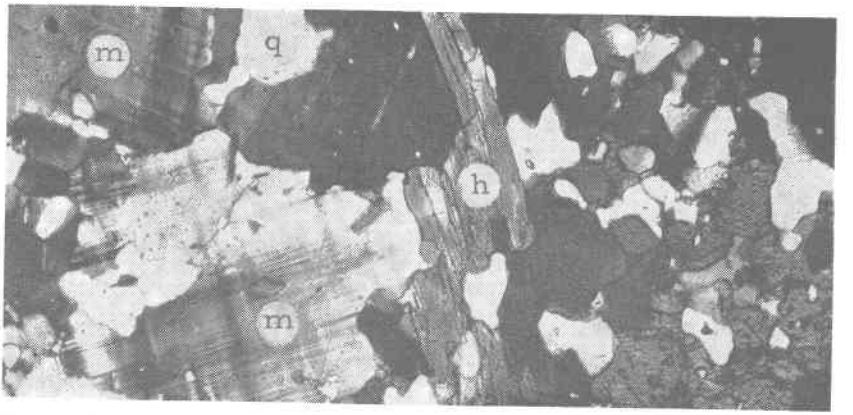

Figure 12. Photomicrograph of granite of the Robertson River formation at cut in U. S. Highway 29 north of Rapidan River, Madison County. Microcline (m), hornblende (h), and quartz (q). Crossed nicols. X 55.

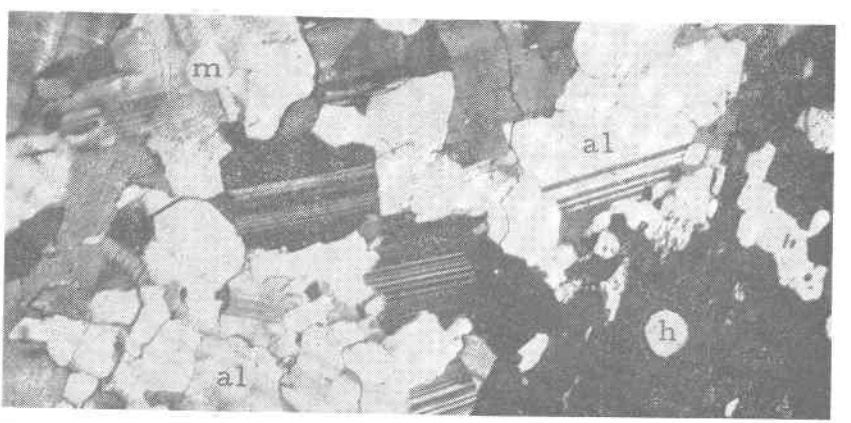

Figure 13. Photomicrograph of granite of the Robertson River formation in quarry west of State Road 687 near Pratts, Madison County. Albite (al), microcline (m), and hornblende (h). Crossed nicols. X 55.

ROBERTSON RIVER FORMATION

Name and Distribution

The name Robertson River formation is suggested for the northeastward-trending exposures of hornblende granite and hornblende syenite that crop out roughly parallel to U. S. Highway 29 throughout Greene and Madison counties. The name Robertson River was selected because good exposures of this formation occur along the valley walls of this stream northeast of Madison. Fresh exposures of this rock are in the road cuts of the U. S. Highway 29 by-pass at Madison. A good, although somewhat weathered, exposure is in the road cut of U. S. Highway 29, just north of the Nathaniel B. Early bridge, on the Madison County side of Rapidan River. Numerous exposures exist along the valley slopes of Whiteoak Run, just northwest of Madison.

Caliga (1948) recognized a hornblende granite in the Ruckersville area and described the petrology of such rocks that crop out in the vicinity of Spring Hill Church on State Road 641 approximately 0.5 mile west of U. S. Highway 29 in Albemarle County.

The Robertson River formation is about 1.5 miles wide in Greene County and crops out on both sides of U. S. Highway 29. The outcrop widens to about 3 miles in the vicinity of Shelby, Madison County, and to the northeast of Madison it is approximately 4 miles wide. The Robertson River formation is in contact with the Lovingston formation along its northwest border and with the Lynchburg formation on the southeast. In the Brightwood area (Madison County) a zone of Lovingston lies to the southeast of the Robertson River formation. Southeast of the Robertson River-Lynchburg contact, outliers of Robertson River are within the Lynchburg formation.

Contact with the Lovingston formation is gradational over a distance of 0.25 to 0.5 mile. In the field the change from Robertson River formation to Lovingston formation is marked by the disappearance of hornblende and the development of a strong gneissic structure and prominent augen in the Lovingston. Contact with the Lynchburg formation is generally sharp and marked by a silicified zone. A well cemented clastic layer, with minor conglomerate lenses, commonly occurs between it and the Lynchburg.

Lithology

The Robertson River formation is uniform in its appearance on outcrop. Fresh rock has a grayish-white color, and weathered surfaces are white, with brownish strain from the alteration of hornblende. For the most part the rock type, or facies of the formation, is a hornblende-

oligoclase granite. The texture is medium to coarse with some minor gneissic foliation. Feldspar, quartz, and hornblende are readily observed in hand specimen although hornblende constitutes only approximately 10 percent of the rock.

Samples from the granite facies which were examined with a microscope contain predominantly potassic feldspar (orthoclase, perthite and minor microcline), sodic oligoclase (from 10 to 15 percent), shredded green hornblende and small wisps of actinolite, clear quartz, scattered biotite shreds mostly altered to chlorite, and scattered grains of apatite and sphene (Figures 12, 13). Oligoclase masses contain some epidote, and rims and veinlets of albite penetrate minute fractures between quartz and feldspar crystals. Small micropegmatitic veinlets are present throughout much of the granite facies. East of Shelby a zone of Robertson River formation contains about 50 percent potassic feldspar, about 20 percent sodic andesine, approximately 20 percent quartz, about 10 percent ilmenite and magnetite, shreds of biotite and muscovite, and a few scattered grains of almandine garnet and hornblende. The Robertson River formation has a syenite facies that is exposed along State Highway 321 paralleling Robertson River about 4 miles north of Madison. In this area, and northeastward across Robertson River and south of Haywood, the rock is composed essentially of feldspar and greenish-black hornblende, with little to no quartz visible in hand specimen. The syenite facies along State Highway 231 in the Mulatto Run area contains approximately 10 to 15 percent green hornblende altered to biotite; less than 12 percent sodic oligoclase; 2 to 3 percent quartz; and perthitic orthoclase, as large crystals (up to 1 cm). Small crystals of sphene and leucoxene-bordered ilmenite grains are common.

Shearing is prevalent throughout the Robertson River formation. This is particularly noticeable in the cataclastic structure developed in the plagioclase crystals, a condition present in both the granite and the syenite facies. Potassic feldspar appears less sheared and broken than plagioclase. Minor fractures are filled and minute broken fragments of feldspar are cemented by albite and quartz. Introduction of titanium minerals and apatite appears to have taken place at approximately the same time as quartz and albite.

LYNCHBURG FORMATION

Name and Distribution

The Lynchburg formation, named for the exposures of gneiss and schist in the vicinity of Lynchburg, Virginia (Jonas, 1927, p. 845) and considered by Brown (1958, p. 18) as a rock unit, is exposed over a wide

area in the eastern parts of Greene and Madison counties. The Lynchburg formation is exposed in an area about 2 miles wide along the easternmost margin of Greene County. This formation is in contact with the Robertson River formation along its northwest border. Small hornblende granite outliers of Robertson River formation are within the Lynchburg. In Madison County, the northwest border of the Lynchburg is in contact with the Robertson River formation. Several small exposures of Lovingston are in the Lynchburg formation northeast of the town of Madison. West of the Rapidan River in southern Madison County the Lynchburg formation is in fault contact with Triassic formations. Dike- and sill-like bodies of ultramafic rock and amphibolite dikes intrude the Lynchburg in eastern Madison County. In this report the Lynchburg formation is considered Precambrian.

Lithology

Several of the rock types described by Brown (1958) in the Lynchburg area are present in Greene and Madison counties. In the Warrenton quadrangle, approximately 15 miles northeast of Madison County, rocks mapped by Furcron (1939) as Fauquier and Loudoun formations show lithologic similarity, in part, to the Lynchburg formation of Greene and Madison counties.

The most prevalent rock types of the Lynchburg formation in the Greene-Madison area are biotite-muscovite schist and phyllite, and biotite-muscovite-chlorite-quartz gneiss. Minor amounts of graphitic schist and garnetiferous schist and one occurrence of conglomeratic gneiss are present. Phyllites and mica schists are the predominant facies of the Lynchburg formation in eastern Greene County. The fine- to medium-grained phyllites and schists are light gray to yellowish gray on fresh exposures and yellowish tan to rusty brown on weathered outcrops. Porphyroblasts of almandine garnet are locally abundant in the more schistose rocks. The phyllitic and schistose layers have well-developed foliation and poorly defined bedding.

Gneissic layers make up a prominent facies of the Lynchburg in Madison County. The layers are light to dark gray and generally medium grained. Cross-bedding is common, and graded bedding is apparent in some outcrops (Figures 14, 15, 16). Gravel layers, that impart a conglomeratic appearance, occur in well-defined zones or beds. Much of the rock lacks a characteristic gneissic structure and could be classified as a metamorphosed graywacke. Small discoid fragments of graphite and amphibole schist are common in the gneissic or graywacke

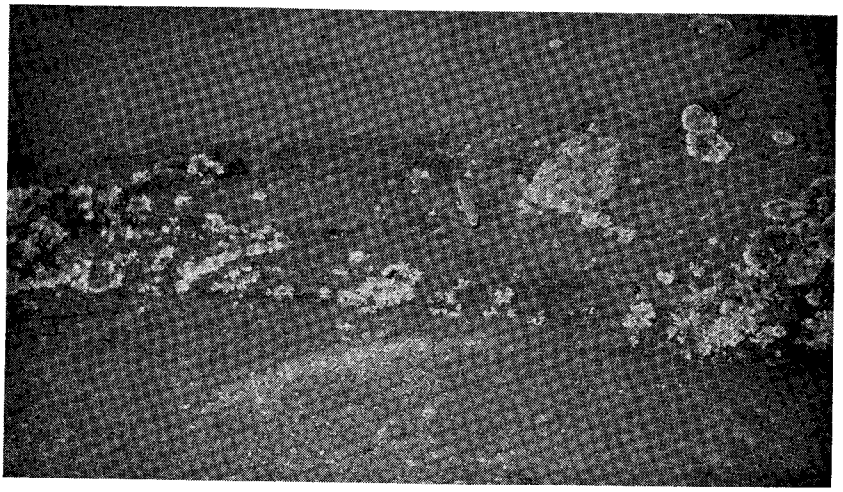

Figure 14. Lynchburg formation containing angular cobble of quartzite, pebbles of quartz and gneiss, and fragments of phyllite and schist, south flank of Thoroughfare Mountain, Madison County.

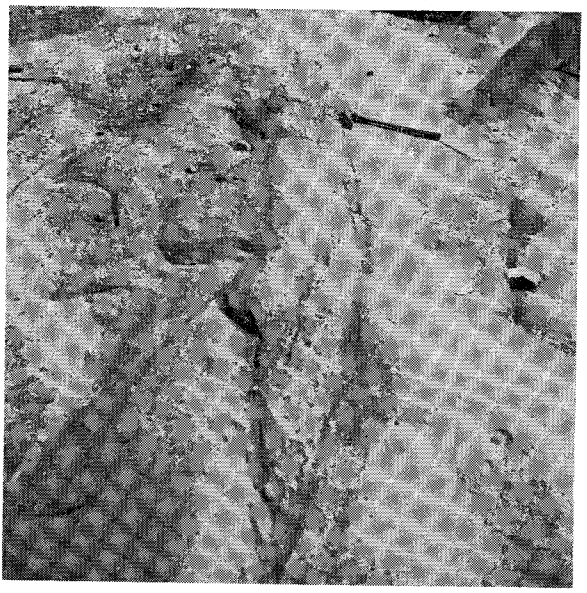

Figure 15. Metamorphosed graywacke of the Lynchburg formation south of State Road 610, Greene County. Quartzite inclusion (center) shows possible cross-bedding.

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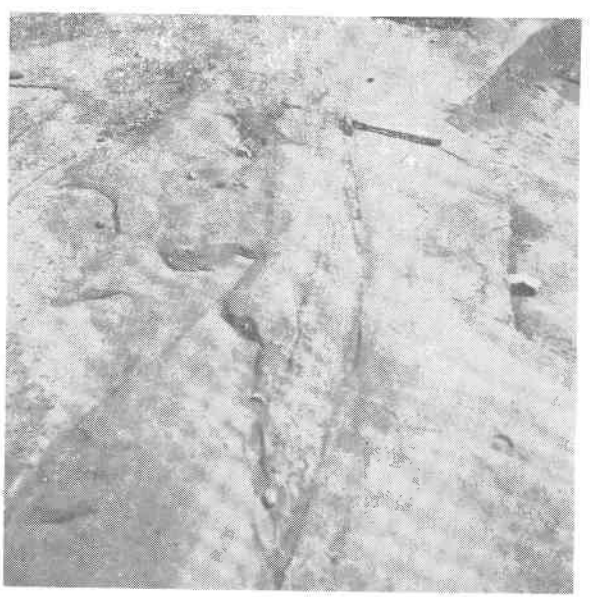

Figure 15. Metamorphosed graywacke of the Lynchburg formation south of State Road 610, Greene County. Quartzite inclusion (center) shows possible cross-bedding.

Figure 16. Lynchburg formation with graded bedding and inclusions of graphite schist east of State Road 634 and southeast of Oakpark, Madison County.

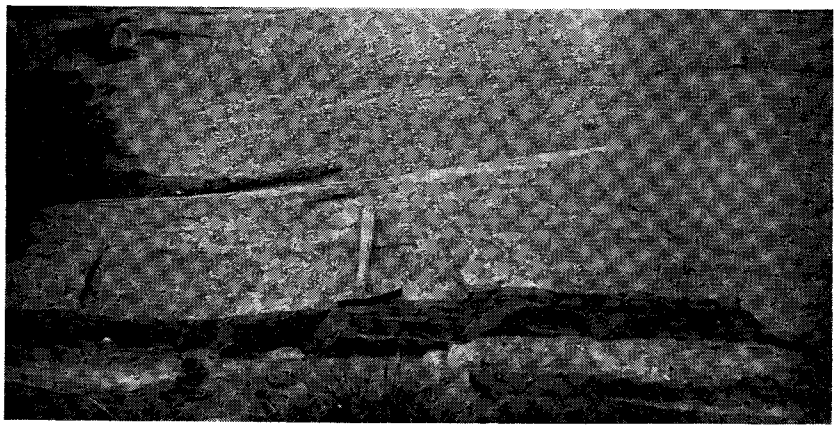

Figure 17. Metamorphosed graywacke of the Lynchburg formation containing large slab of graphite schist, just east of State Road 634 southeast of Oakpark, Madison County. Note cross-bedding.

Figure 16. Lynchburg formation with graded bedding and inclusions of graphite schist east of State Road 634 and southeast of Oakpark, Madison County.

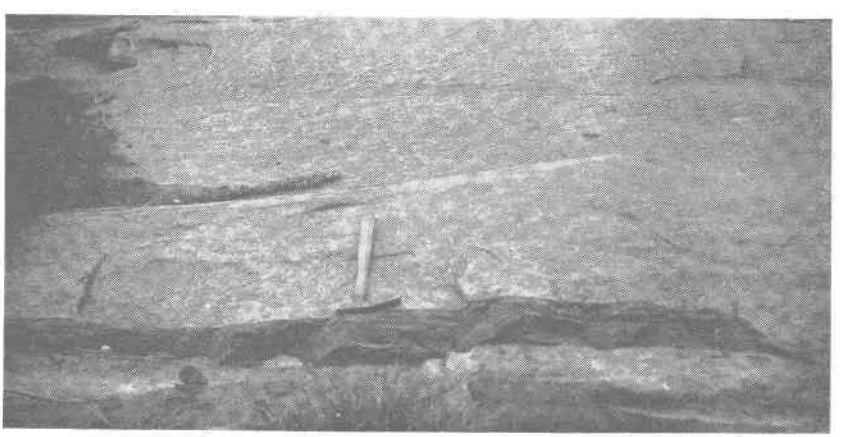

Figure 17. Metamorphosed graywacke of the Lynchburg formation containing large slab of graphite schist, just east of State Road 634 southeast of Oakpark, Madison County. Note cross-bedding.

facies, and at one locality large slabs of graphite schist occur as inclusions (Figure 17). The gneissic, or metamorphosed graywacke, layers are composed of quartz, muscovite, biotite, potassic feldspar, plagioclase feldspar, sericite and chlorite, small grains of epidote, zircon, sphene, and almandine garnet (Figure 18).

There are a number of excellent exposures of the metamorphosed graywacke, or gneissic, facies of the Lynchburg formation. In Greene County, good exposures of gneissic graywacke are present along U. S. Highway 33 approximately 500 yards southeast of Bethany Church, along the valley of Rippin Run, and along State Road 610 approximately 1 mile northeast of Newtown. In Madison County the gneissic graywacke exposures are more numerous and the beds are thicker. Excellent outcrops occur on State Road 702 at the ford across Robertson River near the site of the small electric generating station, at Repton Mills on State Road 607 and along State Road 640 about 2 miles northwest of Leon Post Office. Pebbly or conglomeratic graywacke gneiss (Figure 14) is exposed in Madison County along State Road 630 parallel to the south slope of Thoroughfare Mountain, north of State Road 634 between the road and Robertson River in the Oakpark area, and along State Road 635 between State Roads 614 and 634. These exposures of gneissic graywacke contain rounded pebbles and discoid fragments of schist (usually graphitic), blue and white quartz, feldspar, chert, quartzite, and weathered granitoid and gneissic material. An interesting breccia occurs in the Lynchburg formation on the summit and northwest flank of Thoroughfare Mountain. Here the Lynchburg is arkosic, coarse grained, massive, and contains discrete angular fragments of well indurated, uniform-grained, white sandstone and large quartz fragments. The fragments measure as much as 1 inch in longest dimension, and seldom are smaller than 0.25 inch along an edge.

Large slabs of schist are present in the Lynchburg formation about 1 mile east of Oakpark, and approximately 0.25 mile north of State Road 634. Several slabs of graphitic schist, about 5 feet long and 6 inches wide (Figure 17), and many smaller fragments, can be seen. The Lynchburg formation at this locality shows excellent cross-bedding, some graded bedding, and may represent deltaic slumping or submarine-landslip accumulations at the time of formation of the Lynchburg sediments.

A graphite schist facies of the Lynchburg formation is well exposed in a shallow cut along State Road 634 about 100 yards south of the junction with State Road 706 (abandoned). The zone of graphite schist is continuous southwestward, parallel to the large body of ultramafic rock intrusive into the Lynchburg, and can be traced through

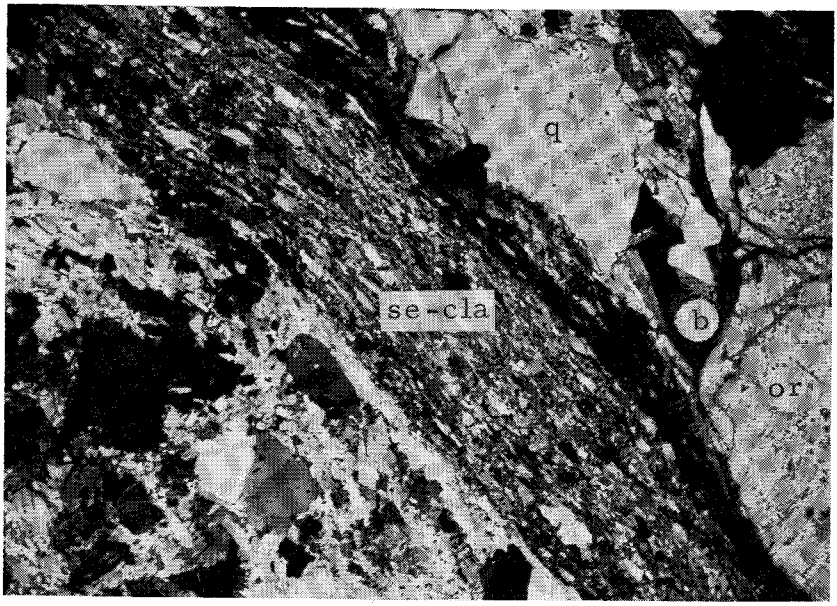

Figure 18. Photomicrograph of metamorphosed graywacke of the Lynchburg formation along State Road 618 at Crooked Run, Madison County. Small sericite and clay veinlet (se-cla) cuts quartz (q), orthoclase (or), and biotite (b). Crossed nicols. X 55.

Figure 19. Conglomerate of the Lynchburg formation containing cobbles of gneiss in roadcut along State Highway 230 south of Uno, Madison County.

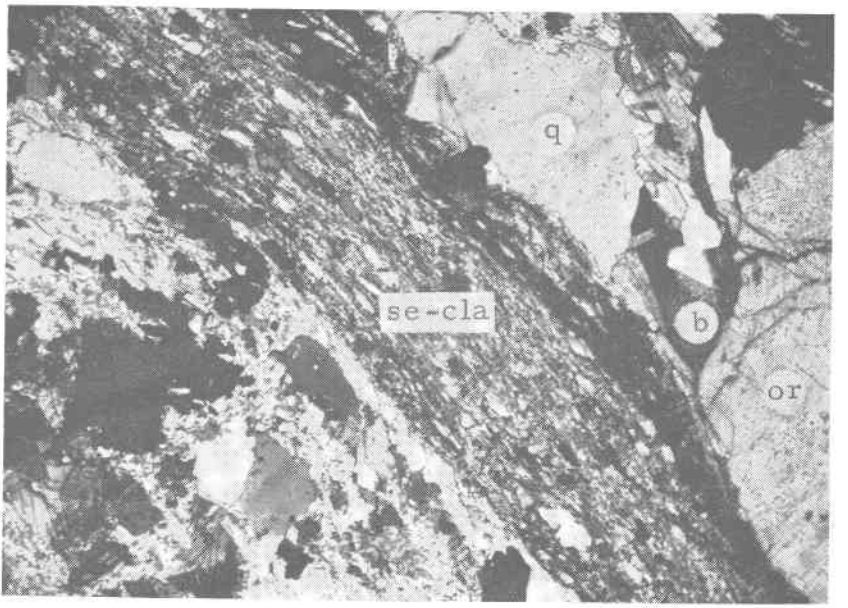

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Figure 19. Conglomerate of the Lynchburg formation containing cobbles of gneiss in roadcut along State Highway 230 south of Uno, Madison County.

Achsah Post Office, Twymans Mill Post Office, and to the south of State Highway 230. An especially good exposure of graphite schist is present in Madison County at (or near) the intersection of State Highway 230 and State Roads 684 and 705. Small layers of graphite schist occur along State Road 700 between State Highway 230 and State Road 616; southwest of State Highway 231 this facies of the Lynchburg formation apparently is present only in minor lenses.

Two small exposures of cobble conglomerate are present near Uno. One is in a small cut along State Highway 231 about 200 yards southeast of the junction with State Road 620, and the other is in the drainage ditch along State Road 620 approximately 100 yards east of the junction with State Highway 231. Cobbles of weathered granitoid and gneissic rock, well rounded and from 4 to 6 inches in diameter (Figure 19) are inclosed in a weathered matrix of sandy and clayey material. This conglomerate contains much larger rock fragments than the conglomeratic beds noted elsewhere in the Lynchburg formation and may be correlative with the Rockfish conglomerate; however, the conglomerate at Uno appears to be higher in the section. Table 2 has approximate modes for three samples of Lynchburg formation.

Table 2.—Approximate modes of metamorphosed sedimentary rocks (in percent)

	Loudoun formation	Swift Run formation			Mechum River formation		Lynchburg formation		
	1	2	3	4	5	6	7	8	9
Quartz	60	40	50	62	56	15	47	13	19
Potassic Feldspar	3	X	8	2	X	35	10	25	27
Plagioclase (An_{20-50})	2	20	4	X		25	5	35	32
Biotite	—	—	2	—	10	5	25	22	20
Muscovite	5	40	10	5	2	13	10	5	2
Sericite-clay	30	—	25	2	2	—	—	—	—
Epidote	—	—	—	29	—	2	1	—	—
Chlorite	—	—	—	—	20	2	—	—	—
Sphene	—	—	—	—	—	X	2	—	—
Garnet	—	—	X	—	4	—	—	X	—
Ores	X	—	1	X	1	3	—	X	X

X Present in less than 1 percent.
1. Milepost 79, Skyline Drive.
2. Powell Gap, Skyline Drive.
3. Near Milepost 58, Skyline Drive.
4. Broken Back Mountain, State Road 614, Greene County.
5. Quarter Run, west of State Road 629, Greene County.
6. 0.5 mile west of Ruth School, Madison County.
7. Repton Mills, Madison County.
8. Thoroughfare Mountain, Madison County.
9. Crooked Run, State Road 618, Madison County.

MECHUM RIVER FORMATION

Name and Distribution

The name, Mechum River metasedimentary rocks, was suggested by Gooch (1958) for the metamorphosed rocks that extend northeastward from Batesville, Albemarle County, approximately 60 miles to Ben Venue, Rappahannock County. The Mechum River formation has an outcrop that is 0.5 to 2 miles wide in Greene County and slightly narrower in Madison County. The formation is generally bordered on the northwest and southeast by the Lovingston; masses of Old Rag granite and migmatitic, or mixed, gneisses are in contact with it locally. The formation consists of a main body with small bordering outliers such as are present along the Greene-Albemarle county boundary, along Rapidan River, and in the Gaar Mountain-Robertson River area. The Mechum River, although lithologically similar to the Lynchburg is considered in this report as a separate rock unit of Precambrian age.

Lithology

In Greene and Madison counties the Mechum River units consist chiefly of slightly metamorphosed sandstone, arkose, graywacke and intercalated beds of phyllite. A conglomeratic facies crops out about 1 mile west of Wolftown, Madison County. Low-grade metamorphism of the formation is characterized by vertical to southeastward-dipping secondary foliation and minor recrystallization of quartz and feldspar grains. Sandstones and arkoses grade into each other. Sandstones consist of quartz and minor amounts of plagioclase and potassic feldspar and biotite. Arkosic units have more potassic and plagioclase feldspar than the sandstones. Graywacke units contain quartz, feldspar, chlorite, muscovite and biotite in a finely divided chlorite-sericite matrix. Phyllites are composed of sericite, biotite and minor amounts of quartz and feldspar. Almandine garnet, ilmenite, sphene, zoisite (epidote), and zircon are present in minor, but variable, amounts.

One of the best exposures of Mechum River formation is along the Forest Service Road from Ruth School to Blakey Ridge fire tower (Madison County). The exposed section is only a part of the Mechum River sequence, but it provides an excellent example of the several rock types. In Greene County, excellent exposures of Mechum River units are along Quarter (Deep) Run southeast of Swift Run School and along Henshaw Run north of Eppards Mill. Table 2 has approximate modes of two samples of Mechum River formation.

DIKE- AND SILL-LIKE ROCKS

Dike- and sill-like bodies of amphibolitic and ultramafic rock are in, and are younger than, the Mechum River and Lynchburg formations. Greenstone feeder dikes of the Catoctin formation and Triassic (?) diabase were excluded from this group. Brown (1958, pp. 38-47), in a comprehensive description, commented on the theories of origin of the amphibolitic and ultramafic bodies and described a hornblende gneiss older than the Lynchburg formation and hornblende-rich rocks younger than the Lynchburg formation. Amphibolites in the Greene-Madison area all appear to be post-Lynchburg in age.

Amphibolite

The term amphibolite is applied to rocks composed chiefly of hornblende and plagioclase which have a granoblastic or granitoid texture. These lenticular bodies are generally elongate and parallel to the regional structure, and seldom are more than 1 mile in length and 200 feet in width. Hornblende is present as rough, stubby, closely intergrown crystals about 0.25 inch long; in some places it occurs as lenticular porphyroblasts. The hornblende is enclosed in a matrix of white, granular andesine plagioclase. Minor amounts of quartz, brown biotite, sphene and ilmenite are common. Locally, almandine garnet and interstitial calcite are present (Figures 20, 21). Approximate modes are given in Table 3.

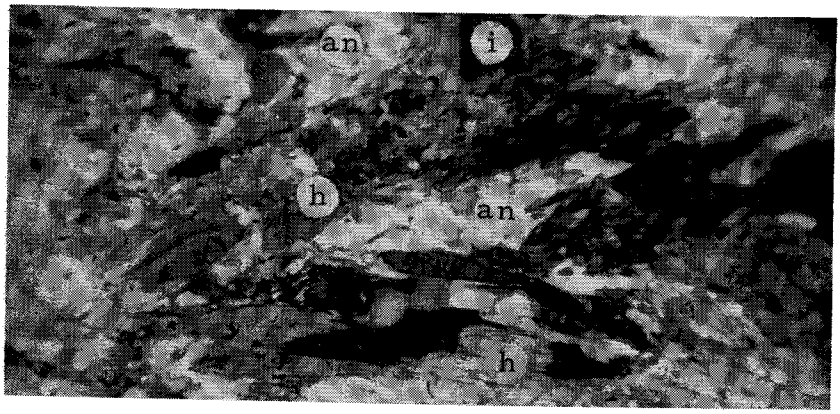

Figure 20. Photomicrograph of amphibolite from the vicinity of Neal Mountain, Madison County. Untwinned andesine (an) in mosaic of hornblende (h) and ilmenite (i). Crossed nicols. X 77.

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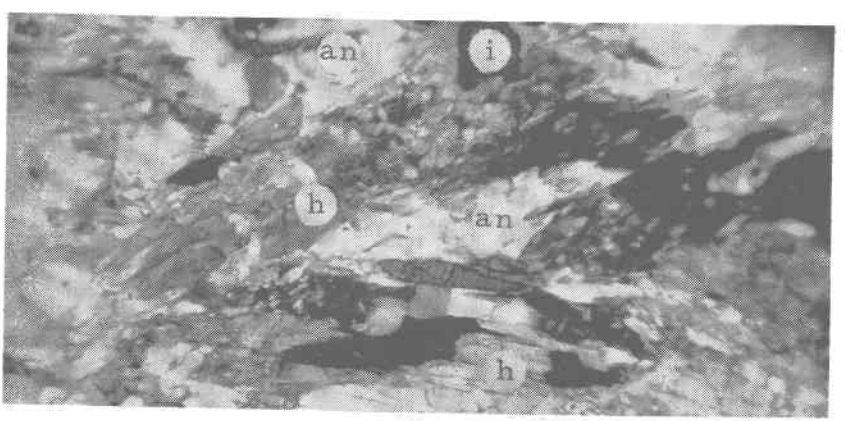

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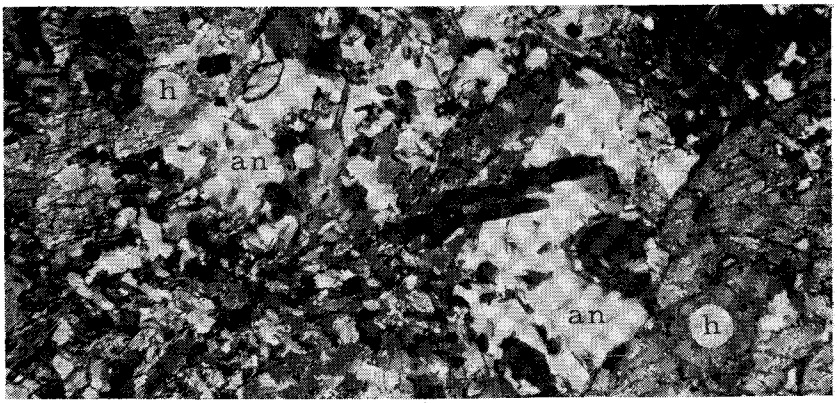

Figure 21. Photomicrograph of amphibolite from a dike near Priddy Creek, State Road 607, Greene County. Hornblende (h) and untwinned andesine (an). Crossed nicols. X 55.

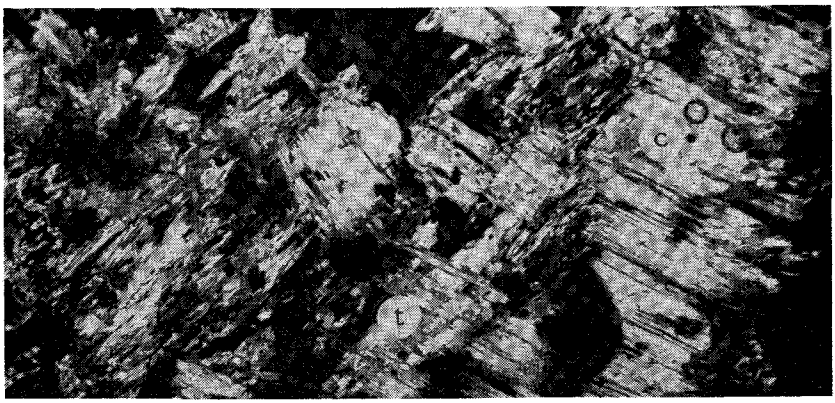

Figure 22. Photomicrograph of ultramafic rock from dike-like body near Fordville, State Road 618, Madison County. Chlorite (c) and laths of tremolite (t) are the major constituents. Crossed nicols. X 55.

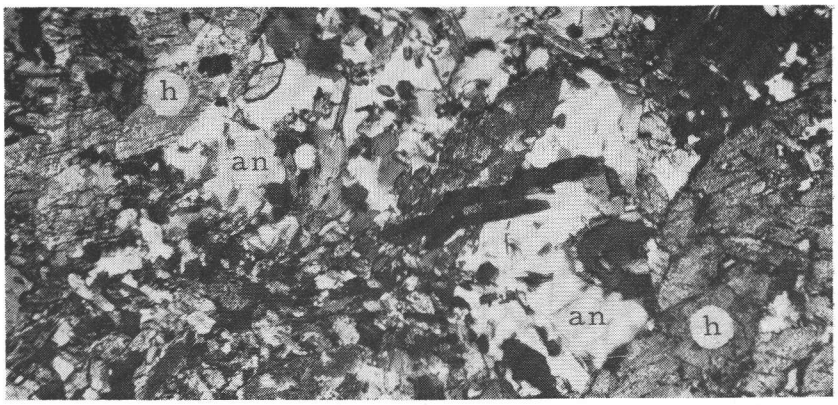

Figure 21. Photomicrograph of amphibolite from a dike near Priddy Creek, State Road 607, Greene County. Hornblende (h) and untwinned andesine (an). Crossed nicols. X 55.

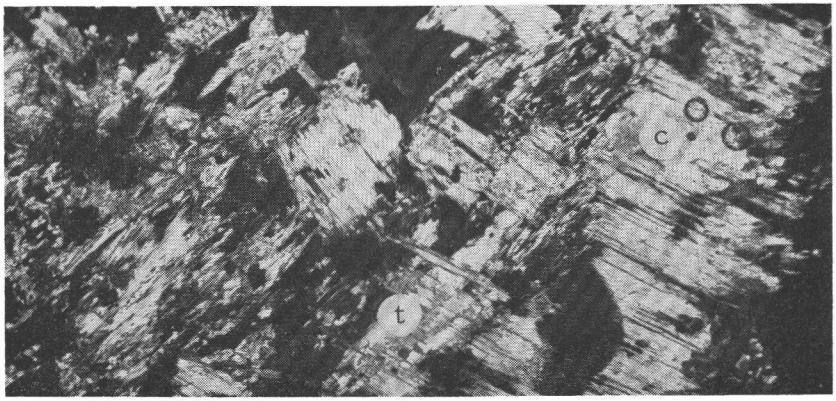

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Table 3.—Approximate modes of amphibolites and ultramafics (in percent).

	Amphibolites						Ultramafic rocks			
	1	2	3	4	5	6	7	8	9	10
Potassic Feldspar	5		X							
Plagioclase	22	45	43	33	23	38	29	—	X	X
Pyroxene	—	—	—	—	—	—	—	—	2	1
Hornblende	68	50	48	62	75	60	—	—	—	—
Tremolite-actinolite	—	—	2	1	X	—	40	50	50	42
Olivine	—	—	—	—	—	—	—	—	X	—
Biotite	—	—	3	—	—	—	—	—	—	—
Chlorite	2	1	2	X	—	X	30	39	40	57
Serpentine	—	—	—	—	—	—	X	4	2	X
Talc	—	—	—	—	—	—	X	2	6	X
Carbonate	—	2	—	—	—	—	—	—	—	—
Scapolite	—	—	—	—	—	—	—	5	X	—
Epidote-clinozoisite	2	1	—	2	2	1	—	X	—	—
Ores	1	1	2	2	X	1	1	X	X	X

X Present in less than 1 percent.
1. State Road 617, at Welsh Run.
2. 2.5 miles south of Ruckersville, U. S. Highway 29.
3. Priddy Creek and State Road 607.
4. End of State Road 640, Greene County.
5. 2 miles east of Wolftown on State Road 663.
6. Neal Mountain, Madison County.
7. End of State Road 712, Madison County (amphibolite and ultramafic complex).
8. Fordville, State Road 618.
9. Achsah, Madison County.
10. Robertson River, north of State Road 634, Madison County.

Generally, the amphibolitic bodies are concordant with bedding of the Lynchburg and Mechum River formations, but there are discordant attitudes. Amphibolites follow the trend of the gneissic structure within the gneissic rock of the Virginia Blue Ridge complex. Many of the contacts with metasedimentary rocks and gneissic and granitoid rocks are gradational, indicating replacement activity. The crystalloblastic texture, so common in the amphibolites, and the presence of garnet and calcite are further indications of replacement. It appears that the amphibolitic material was introduced as fluids that replaced host rock along zones of weakness, such as bedding and fracture surfaces. The dike- and sill-like bodies may have developed by accretionary growth through replacement or metasomatic activity.

Ultramafic Rocks

Ultramafic rocks occur in eastern Madison County as elongate masses within the Lynchburg formation. Plate 1 shows the locations of the groups of ultramafic bodies. Scattered, elongate, dike-like masses occur southwest of State Highway 230 parallel to the regional structure of the Lynchburg formation. Northeast of State Highway 230, near the junction with State Road 705, a continuous body of ultramafic

rock extends for 8 miles through Twymans Mill, Achsah, Fordville and Crooked Run into Culpeper County. The ultramafic bodies southwest of State Highway 230 range from 20 to 100 feet in thickness and from 0.1 to 1 mile in length. The large body in the vicinity of Fordville has an approximate thickness of 1,000 feet. Along the strike, approximately N. 30° E., the ultramafic bodies pinch and swell; and in some places split into two branches that are separated by graphitic schist and phyllite of the Lynchburg formation. This relationship is well defined along State Road 634 southeast of Oakpark.

Most of the ultramafic masses are slightly foliated, medium to coarsely crystalline and porphyroblastic. The rock, gray to greenish gray on fresh surfaces, becomes dark green upon weathering. Variations in mineralogic composition are reflected in the color of the outcrop; some peridotitic bodies are dark gray to greenish black. Most of the ultramafic bodies are classed as amphibole-chlorite schist, though foliation is lacking in many places. The schists contain approximately equal amounts of tremolite-actinolite and chlorite. Schistosity increases with an increase of chlorite content. Tremolite is the most common amphibole (Figure 22), and in some instances is the sole rock constituent. Small masses of peridotite, characterized by a greenish to bluish-black color and small grains of brownish-green olivine, occur. A few of the outcrops adjacent to the Lynchburg formation contain plagioclase (oligoclase-andesine range) and quartz. By use of X-ray emission the presence of iron, chromium, zirconium and titanium was determined. Altered crystals of scapolite have been identified by thin section and X-ray diffraction in the ultramafic mass that extends from Achsah to Fordville and Crooked Run. Approximate modes of several samples from ultramafic bodies are given in Table 3.

The ultramafic rocks in Madison County are essentially a northeastward continuation of those in Campbell and Amherst (Brown, 1958, pp. 41-47) and Nelson and Albemarle counties (Watson, 1907, pp. 293-296). These include the well-known serpentine-soapstone deposits of Schuyler, Virginia, and the "Virginia Greenstone" of Lynchburg, Virginia (dark-green actinolite and chlorite). Ultramafic masses that contain talc and serpentine are also present; with an increase in the quantity of talc, they have a light greenish-gray color and a slick feel. Locally, the masses have been called "soapstone," but this material is limited in occurrence. Suggested origins of the ultramafic rocks in this elongate northeastward-trending belt have been advanced by Burfoot (1930), Hess (1933), and Brown (1958). The stratigraphic position of these rocks within the Lynchburg formation could not be ascertained because of their proximity to the Triassic border faults.

The ultramafics may represent altered flows or intrusives. The age of these rocks is no older than the Lynchburg and no younger than the Catoctin formation.

CAMBRIAN OR PRECAMBRIAN ROCKS

Agreement as to the boundary between the Precambrian and Cambrian rocks in the Blue Ridge area has not been reached. From studies of the rock units in the Elkton area, King (1950, p. 14) wrote:

> "The writer considers the Catoctin greenstone to be late pre-Cambrian in age. It lies unconformably beneath Lower Cambrian rocks, which are themselves about 3,000 feet beneath beds containing the earliest Lower Cambrian fossils. . . . The writer concludes that, in the Elkton area, at least, the differences of the Catoctin and Swift Run formation from the overlying Chilhowee group are greater than the similarities, suggesting that the two units are parts of different geologic cycles, one of the pre-Cambrian and the other of Early Cambrian age."

From his studies in the Lynchburg quadrangle, Brown (1958, p. 18) concludes that the Catoctin and Lynchburg formations of Late Precambrian age are strictly rock units with only general time connations. Bloomer and Werner (1955, pp. 581-593) place the Swift Run formation and Catoctin formation in the Late Precambrian. Reed (1955, pp. 895, 896), from his studies of the Catoctin in the Luray, Virginia area, states:

> "A period of weathering which formed a saprolite up to 150 feet thick may have followed the end of Catoctin vulcanism, but no evidence was found in the Luray area of a major time interval between the Catoctin and the Chilhowee. The Catoctin may therefore be at least in part early Cambrian. . . . The present study indicates, however, that the Catoctin lavas resemble basalt accumulations characteristic of [nonorogenic] areas, and that they should not be considered as belonging to the Appalachian geosynclinal cycle. The Catoctin greenstones are probably remnants of a great basaltic plateau which foundered beneath the advancing early Cambrian seas during the initial stages of formation of the Appalachian geosyncline."

Whitaker (1955, pp. 439-441) in a study of South Mountain and Catoctin Mountain in Maryland and northern Virginia is of the opinion that the Catoctin volcanics are conformable and closely related in time to the overlying Chilhowee rocks and perhaps the base of the Catoctin represents the base of the Cambrian.

These views, coupled with the suggestion of Gooch (1958, p. 574) that the Swift Run and Lynchburg formations and the Mechum River formation are at least in part equivalent, contain varied opinions concerning the age of these rock units. Consequently, the Swift Run and Catoctin formations are designated Cambrian or Precambrian.

SWIFT RUN FORMATION

Name and Distribution

Swift Run formation was applied by Stose and Stose (1946, pp. 18-20) to a heterogeneous unit of sedimentary material that unconformably overlies the "injection complex" (Pedlar formation) and is overlain by the Catoctin formation. This sedimentary unit was described by Jonas and Stose (1939, pp. 583-587). The type locality is in Greene County about 1 mile southeast of Swift Run Gap on the old U. S. Highway 33 and about 200 feet above the present highway location. King (1950, pp. 9-12) used the term Swift Run formation for sedimentary and pyroclastic rock lying between the Virginia Blue Ridge complex and the Catoctin formation. Reed (1955, pp. 880-881) included sedimentary material at the base of the Catoctin as a basal sedimentary member and does not recognize the Swift Run as a formation. Similar sedimentary rocks near Rockfish Gap were named by Bloomer and Bloomer (1947) the Oronoco formation.

In Greene and Madison counties the Swift Run formation appears to be a nearly continuous unit that is overlain by the Catoctin and unconformably overlies the Virginia Blue Ridge complex. Excellent exposures in Greene County are at the type locality just above U. S. Highway 33, in Fork Hollow, in Mutton Hollow, and on Turkey Ridge. One of the best exposures is on State Road 632 west of Victory School. In Madison County the formation is thinner, and exposures are less numerous. Thin beds of Swift Run formation occur in the area south of Skyland. Small masses of intensely sheared Swift Run occur along the fault that extends from Nethers southwestward to Dark Hollow. The formation is thin or absent in northeastern Greene County and on the headwaters of Rapidan River in Madison County. Small inliers of Swift Run formation have been found, and a small mass of what appears to be Swift Run formation occurs in the Lovingston formation southwest of Dyke in Greene County.

Lithology and Thickness

The lithology and character of the Swift Run formation are heterogeneous. Erosion of the Virginia Blue Ridge complex in pre-Catoctin time developed a surface having up to 1,000 feet of relief. The heterogeneous, coarse, clastic material derived from erosion of the Virginia Blue Ridge complex and the volcanic debris of the early stages of Catoctin volcanism developed a complex sedimentary accumulation. Much of the Swift Run is a well-bedded white, pink or purplish arkosic

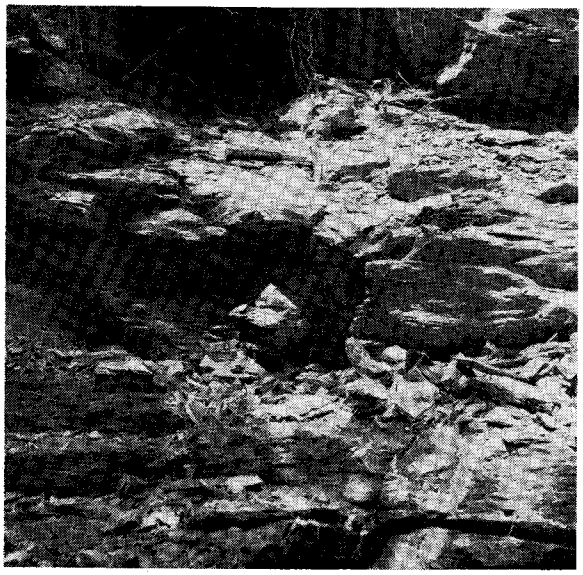

Figure 23. Flagstone quarry in Swift Run formation along State Road 634 near Lydia, Greene County.

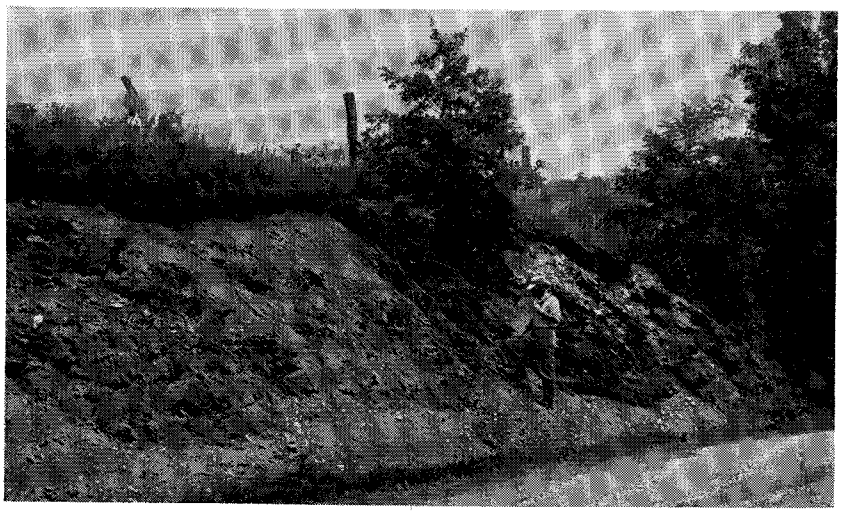

Figure 24. Swift Run formation composed of intercalated phyllites and thin flows along State Road 810 near Boonville, Albemarle County.

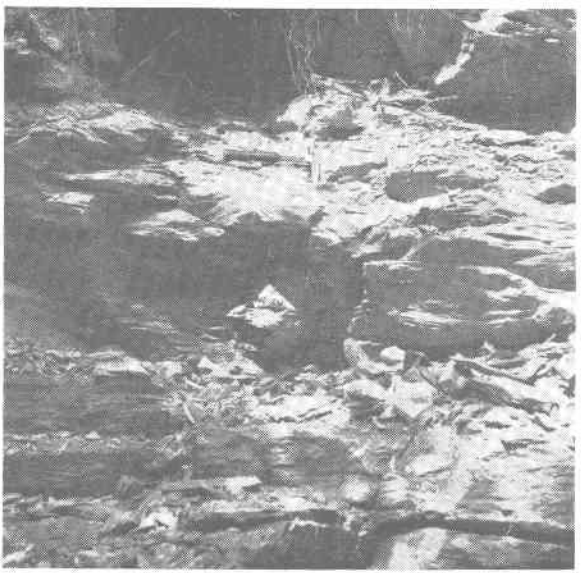

Figure 23. Flagstone quarry in Swift Run formation along State Road 634 near Lydia, Greene County.

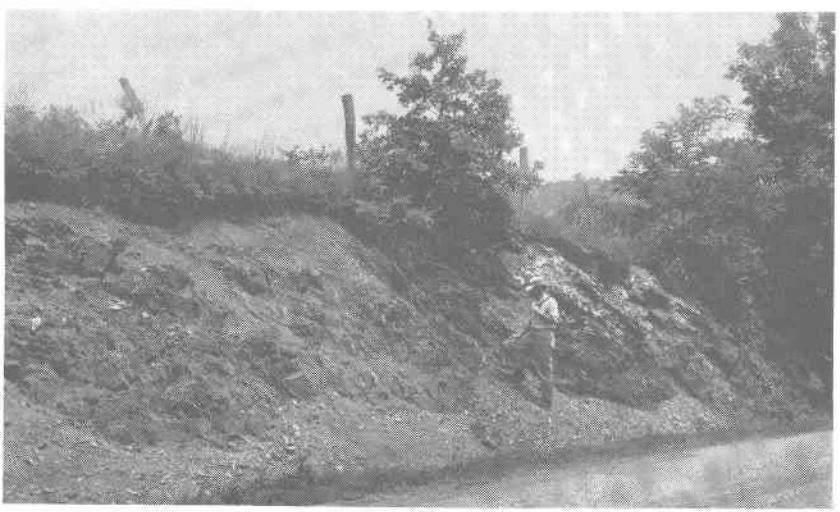

Figure 24. Swift Run formation composed of intercalated phyllites and thin flows along State Road 810 near Boonville, Albemarle County.

quartzite. White and blue quartz and white and pink feldspar are present. Conglomeratic layers interbedded with quartzite, and quartzite interbedded with reddish slates are common. In the Lydia area (Greene County) the intersection of bedding and cleavage surfaces is such that the rock will break into flagstone-like slabs (Figure 23). The upper part of the Swift Run formation contains thin layers of pyroclastic debris and thin flows (Figure 24). King (1950, p. 10) considers the upper contact of the Swift Run to be at the base of the lowest massive greenstone. X-ray examination of the most common facies of the Swift Run formation, a coarse arkosic quartzite, indicates that the rock is composed of about 40 percent quartz, 40 percent muscovite and sericite, and 20 percent plagioclase feldspar. Epidote and minor amounts of chlorite are common matrix constituents. Table 2 has the approximate modes of three Swift Run samples.

The relief of the pre-Catoctin surface in Whiteoak Canyon is 450 feet, and in Hogcamp Branch (head of Rose River) it is 750 feet (Reed, 1955, p. 881). In these areas the Swift Run is more than 100 feet thick. In Greene and Madison counties the Swift Run formation ranges from 10 to 50 feet in thickness. Nelson (1962, pp. 22-24) reports thicknesses exceeding 1,000 feet for the Swift Run formation in western Albemarle County. In southwestern Greene County, deeply weathered Pedlar and Lovingston formations closely resemble the arkosic facies of the Swift Run and are difficult to distinguish from each other. The Swift Run formation is probably conformable with the overlying Catoctin.

CATOCTIN FORMATION

Name and Distribution

Keith (1894, pp. 306-309) applied the name Catoctin schist to exposures in Catoctin Mountain, Maryland. Jonas and Stose (1939) termed similar rock in Virginia, metabasalt. King (1950, p. 12) from his studies in the Elkton area, gave preference to the term Catoctin greenstone as was used on the Geologic Map of Virginia (1928). Reed (1955), who has made the most comprehensive study of the Catoctin in northern Virginia, used the term Catoctin formation and included within that unit the underlying Swift Run formation and overlying Loudoun formation. For this report the writer prefers to designate the Swift Run and Loudoun formations as separate rock units. Following King (1950) and Brent (1960), the flows and associated volcanic rocks that overlie, and are younger than, the Virginia Blue Ridge complex and Swift Run are mapped as Catoctin.

The Catoctin formation crops out along the crest and southeast slope of the Blue Ridge in the western part of Greene and Madison counties. It is also exposed in the extreme eastern part of Madison County. In western Greene County from the Albemarle County line to the vicinity of Powell Gap, a broad exposure of Catoctin covers the crest of the Blue Ridge at Loft Mountain and Flattop. The Roach River has cut down into the underlying Pedlar formation, and its valley almost separates the Catoctin on Flattop from the broad exposure on Hightop. To the northwest of Hightop, the exposure of Pedlar formation along the Skyline Drive from Powell Gap northeastward to the head of Hensley Hollow (Rockingham County) separates the Catoctin formation on Hightop from that along the northwest slope of the Blue Ridge in Rockingham County. Swift Run Gap and the deep valley of eastward-flowing Swift Run are in Pedlar formation and separate the Catoctin on Hightop from the broad exposure of Catoctin in the Saddleback Mountain-Upper Pocasin Mission area. Several small outliers of Catoctin are present in the vicinity of Lydia, and a large outlier is present along the Greene County side of the Conway River west of Kinderhook and Fletcher.

From Hazeltop northeastward to Stony Man the exposure of Catoctin in the Madison County side of the Blue Ridge forms a narrow outcrop. The Catoctin is approximately 3 miles wide in the Spitler Hill area. To the east and southeast of Spitler Hill the Catoctin is faulted against the Pedlar formation and Old Rag granite. Hills of granitic rock of the Virginia Blue Ridge complex have been exposed by erosion of the Catoctin in Whiteoak Canyon and along Hogcamp Branch at the head of Rose River.

Feeder dikes of Catoctin (Figure 25) are present in Mutton Hollow near the junction of State Roads 634 and 635 (Greene County), along Swift Run, and in roadcuts of State Road 626 northwest of Geer. Good exposures are along Rapidan River (Madison County) at the Shenandoah National Park boundary approximately 5 miles north of Graves Mill. Other feeder dikes of Catoctin are present on Fork Mountain, Graves Mountain, Robertson Mountain, and Old Rag Mountain. Several dikes, that closely resemble Catoctin, occur in the Pedlar formation between Hughes River Gap and the Madison-Rappahannock county line.

In eastern Madison County there is a striking similarity of altered mafic flows and intrusions of Triassic age to the Catoctin formation of Clark Mountain (Orange County). Along the Rapidan River in both Madison and Orange counties the low relief of the topography, flood-plain terraces, and alluvium partially mask the occurrence and make

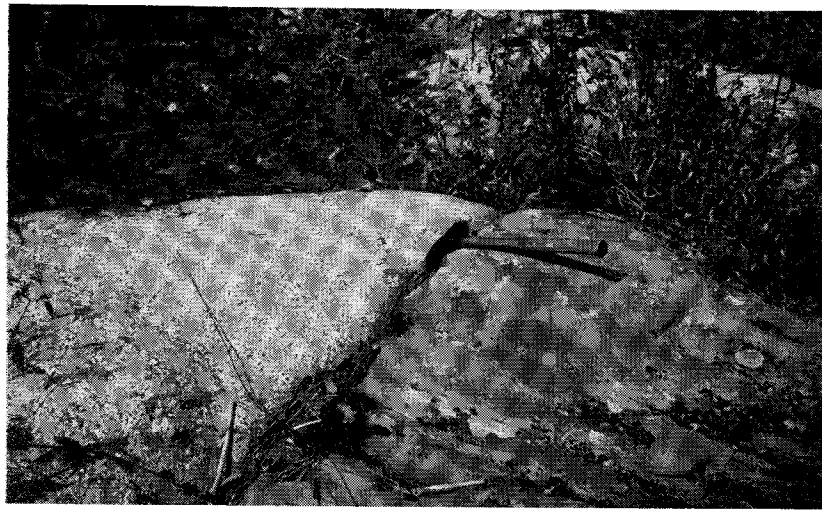

Figure 25. Greenstone feeder dike (under hammer) in Pedlar formation at Mutton Hollow Run near junction of State Roads 634 and 635, Greene County.

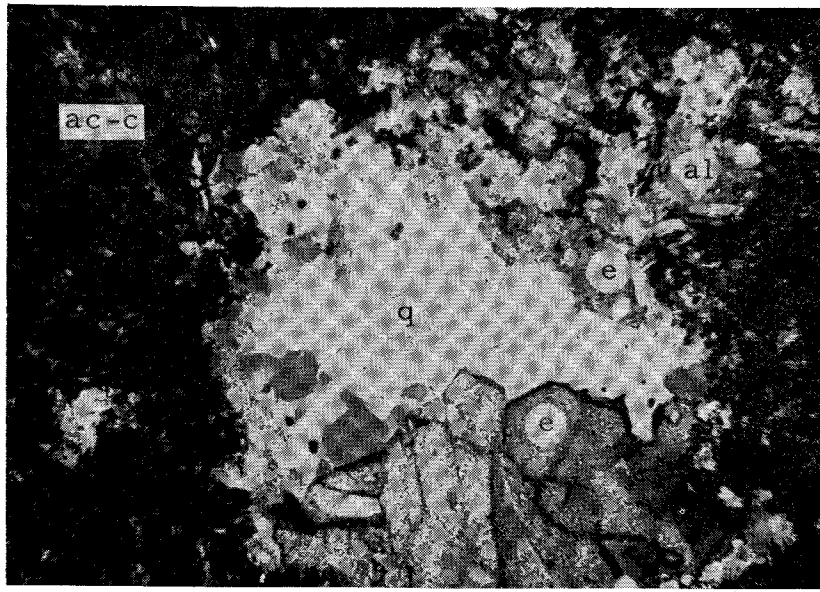

Figure 26. Photomicrograph of greenstone of the Catoctin formation near Pocosin Cabin, Greene County. Amygdule with quartz (q) and epidote (e) in actinolite-chlorite (ac-c) and albite (al) matrix. Plain light. X 55.

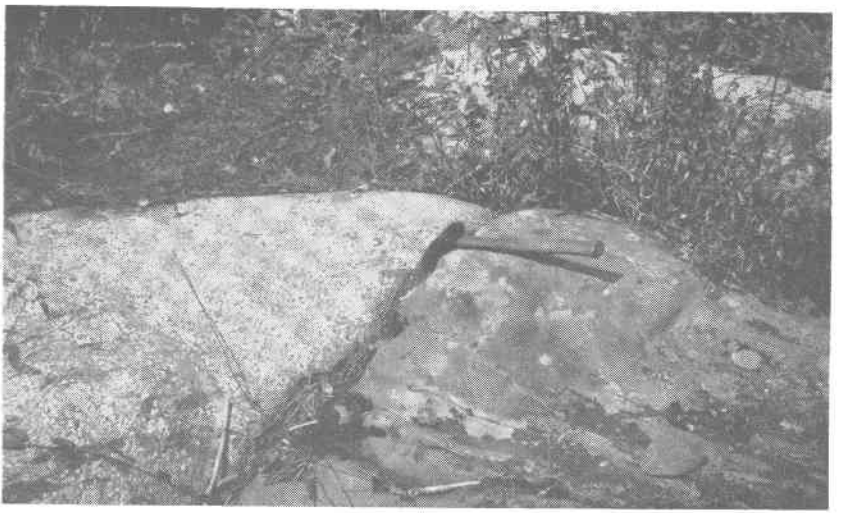

Figure 25. Greenstone feeder dike (under hammer) in Pedlar formation at Mutton Hollow Run near junction of State Roads 634 and 635, Greene County.

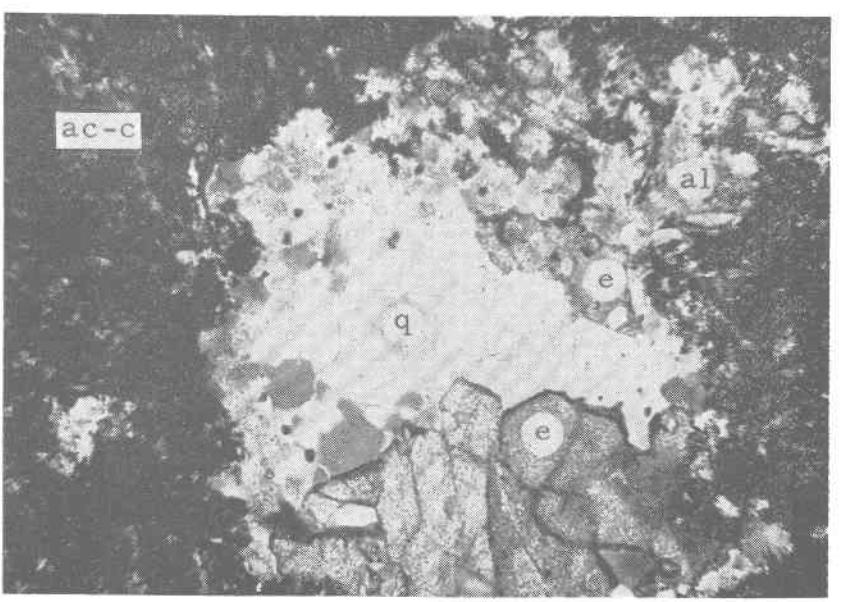

Figure 26. Photomicrograph of greenstone of the Catoctin formation near Pocosin Cabin, Greene County. Amygdule with quartz (q) and epidote (e) in actinolite-chlorite (ac-c) and albite (al) matrix. Plain light. X 55.

identification of the rock units difficult. The massive greenstone-like rock along the east bank of Rapidan River (Orange County) near Madison Mills and Woodberry Forest School closely resembles the Catoctin formation of Clark Mountain. The massive greenstone at the bridge over Rapidan River at the Woodberry Forest School laundry contains plagioclase (An_{2-15}), actinolite, chlorite, epidote, and minor quartz. The presence of sodic plagioclase and absence of pyroxene (probably altered to actinolite and chlorite), indicates that this rock is probably Catoctin. The weathered flows and dike-like masses of mafic igneous rock in Madison County east of State Road 620 have more the appearance of Triassic igneous bodies, and they are intercalated with Triassic conglomerates, sandstones, and shales.

Lithology and Thickness

An excellent and comprehensive description of the facies of the Catoctin formation in the Luray area is given by Reed (1955). King (1950, pp. 12-14) has described the Catoctin along the northwest slope of the Blue Ridge in the Elkton area. Most of the Catoctin formation in Greene and Madison counties consists of altered basaltic flows and associated volcanic agglomerate and pyroclastic sedimentary rocks. The flows are generally dense, massive and dark green to grayish green. Many contain amygdules that are filled with feldspar, epidote, quartz, and zeolites. Quartz and red jasper occur in patches and veinlets, and some of the rock is characterized by segregations of epidote (epidosite). Much of the rock is massive; but a southeastward-dipping cleavage occurs in some of the flows, and some layers show a decided slaty or schistose texture.

Agglomerate masses are common, and layers of sericitic schist and purple to greenish slate, undoubtedly altered tuffaceous material, are intercalated with the flows. A section of southwestward-dipping Catoctin just southwest of Powell Gap has a basal conglomeratic layer containing quartz and jasper pebbles. This is overlain by a purplish-green schist that grades upward into massive greenstone. This exposure shows the usual nature of the transition from Swift Run to Catoctin formations. Porphyritic layers are also present in the Catoctin. A short distance north of Milepost 81 on Skyline Drive an exposure of dark greenstone contains euhedral crystals of pink feldspar up to 1 inch in diameter. Just south of Milepost 61, Skyline Drive, an amygdaloidal flow is exposed; the amygdules are filled with quartz, feldspar, and epidote. Along the Skyline Drive between Mileposts 52 and 53, near Milam Gap, flows contain amygdules that are approximately 0.5 inch in diameter

and consist of green epidote centers rimmed by pink feldspar. Columnar jointing, although relatively uncommon, is present in an exposure on the Appalachian Trail just north of Fishers Gap.

Mineral identification in the Catoctin formation is best accomplished by X-ray examination or by use of thin sections. Minerals generally present are chlorite, epidote, amphibole (actinolite), albite and pyroxene (Figure 26). Magnetite, in sufficient quantity to deflect a compass needle, is present at some localities. Reed (1955, pp. 887-895) has described in detail the mineralogy and petrography of the various facies of the Catoctin, and several of his modal compositions are given in Table 4.

Table 4.—Micrometric analyses of greenstone of the Catoctin formation (Modified from Reed, 1955, p. 889) (in percent)

	1	2	5	8	9	10	11
Albite	27	40	32	32	42	24	21
Chlorite	14	19	5	19	18	7	39
Epidote	3	6	21	10	23	12	4
Actinolite	12	13	16	11	4	21	18
Pyroxene	18	6	3	9	—	7	—
Ores	7	8	18	9	7	10	10
Talc	1	—	—	—	—	—	—
Quartz	1	—	1	—	—	—	—
Sphene and Leucoxene	—	7	4	10	5	18	8

1. Porphyritic greenstone, lower porphyritic flow north of Hawksbill Gap.
2. Coarse-grained greenstone, lower porphyritic flow on south flank of Stony Man.
5. Coarse-grained greenstone, altitude 2390, on north side of Rose River canyon near mouth of Hogcamp Branch.
8. Porphyritic greenstone, Whiteoak Falls fire road just below junction with Skyline Drive.
9. Porphyritic greenstone, lower porphyritic flow on north side of Rose River near mouth of Hogcamp Branch
10. Porphyritic greenstone, upper porphyritic flow near summit of Spitler Hill.
11. Fine-grained greenstone, abandoned quarry along Skyline Drive on south slope of Stony Man.

Reed (1955, p. 888) notes: "Only the pyroxene and part of the magnetite are believed to be primary minerals of the original lava. The albite is pseudomorphic after the original calcic plagioclase." Reed also notes (1955, p. 891) that the plagioclase in the greenstone feeder dikes has a composition in the labradorite (An_{60}) range. Such plagioclase was protected by environmental and grain size conditions so that albitic alteration did not occur. Table 5 has modes of two samples of Catoctin formation in the Blue Ridge and one in eastern Madison County.

Table 5.—Approximate modes of greenstone and other volcanic rocks (in percent).

	Greenstones of the Catoctin formation			Triassic greenstones and other volcanic rocks			
	1	2	3	4	5	6	7
Albite	32	23	30	—	—	—	—
Labradorite	2	—	—	34	30	46	62
Chlorite	20	31	31	3	4	7	X
Epidote	12	15	12	5	5	6	—
Actinolite	17	15	20	X	1	—	—
Pyroxene	6	10	X	58	60	34	35
Biotite	—	—	X	—	—	—	3
Ores	5	3	3	—	—	X	—
Quartz	2	1	3	—	—	—	—
Sphene and Leucoxene	4	2	1	—	—	X	—
Potassic Feldspar	—	—	—	—	—	5	—
Carbonate	—	—	—	—	—	2	—

X Present in less than 1 percent.
1. Porphyritic greenstone near Pocosin Cabin, between Mileposts 59 and 60, Skyline Drive, Greene County.
2. Amygdaloidal greenstone, Milam Gap, Skyline Drive.
3. Greenstone in bluff on east side of Rapidan River, Woodberry Forest School.
4. Diabase (?) Goodall Mountain, Greene County.
5. Greenstone west of State Road 623, 1 mile west o Five Forks, Madison County.
6. Greenstone at Robertson River, on U. S. Highway 15.
7. Gabbro (?) dike, Robertson River, State Road 721, Culpeper County.

Since the original labradorite is characteristically altered to albite in the greenstone of the Catoctin formation, precise mineralogic identifications may be an aid in distinguishing Catoctin from similar Triassic greenstone masses. Microscopic examination of much of the greenstone in eastern Madison County shows calcic andesine and labradorite; albite does not appear to be present. This would indicate that these greenstones are either unaltered Catoctin, or Triassic, and there is no valid reason to assume that this area underwent a lower degree of metamorphism than the area to the northwest. Therefore, a Triassic age has been assigned to these rocks. The greenstones in the vicinity of Woodberry Forest School and along the east side of Rapidan River show sodic plagioclase and actinolite and are considered Catoctin. Table 5 gives approximate modes of samples from the Catoctin formation and Triassic igneous bodies.

The thickness of the Catoctin formation in the Blue Ridge varies considerably. In the western part of Greene County the Catoctin is 1,000 feet or more thick on the crest and east slope of the Blue Ridge. Reed (1955, pp. 880-883) gives a thickness of 1,800 feet at Big Meadows; northwest of Big Meadows the total stratigraphic thickness for seven flows is 1,500 feet. He cites a thickness of 1,800 feet in the Spitler Hill

area and notes that the upper portion of the formation has been removed by erosion. The relief on the pre-Catoctin erosion surface, perhaps more than 1,000 feet, contributes to the variation in thickness present in the Blue Ridge. The original thickness of Catoctin in the Blue Ridge area is unknown, but by combining average thicknesses for the porphyritic and non-porphyritic flows, the total thickness may have been about 2,500 feet.

CAMBRIAN SYSTEM

LOUDOUN FORMATION

Name and Distribution

Keith (1894, pp. 324-329) named the Loudoun formation from exposures in Loudoun County, Virginia, but a specific type locality was not described. On the Geologic Map of Virginia (1928) the term was applied to large areas of rocks thought to be basal Cambrian which occur southeast of the Blue Ridge, extending as far south as Amherst County. It is now known that much of the "Loudoun" southeast of the Blue Ridge lies beneath the Catoctin formation and is, for the most part, Lynchburg formation.

The unit described by Furcron and Woodward (1936, pp. 45-51) as "a basal Cambrian lava flow" that lies unconformably on the Catoctin formation and is overlain by the Loudoun formation in the Blue Ridge area of Page and Rappahannock counties appears to be slaty and schistose rocks of pyroclastic origin and corresponds to the Loudoun in the Elkton area as described by King (1950, p. 16). King doubts that the term Loudoun formation is satisfactory for the beds so described in the northern Blue Ridge area; however, it is not considered feasible at this time to rename and redefine the unit. In Greene County the Loudoun is exposed on the Skyline Drive between Mileposts 75 and 76 and crops out in the headwater valley of Ivy Creek in the vicinity of Pinefield Shelter.

Lithology and Thickness

The characteristic lithology of the Loudoun formation is a purple or reddish, soft slate, containing many oval or round light-green spots (Figure 27). Cleavage is well developed, and bedding is generally evident on the cleavage surfaces. Small breccia fragments are common in bedding layers. Light-gray to green, soft, sericitic slates and schists are intercalated with the purple, green-spotted slates. In Greene County the thickness of the Loudoun is slightly less than 100 feet. Table 2 has an approximate mode of the mineralogy of a sample from the Loudoun formation.

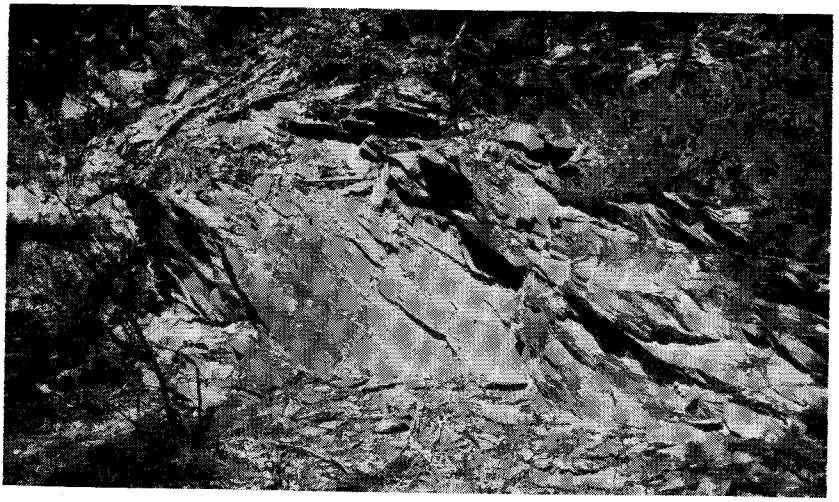

Figure 27. Loudoun formation composed of red slate with green and gray spots, along Madison Run fire road, Shenandoah National Park.

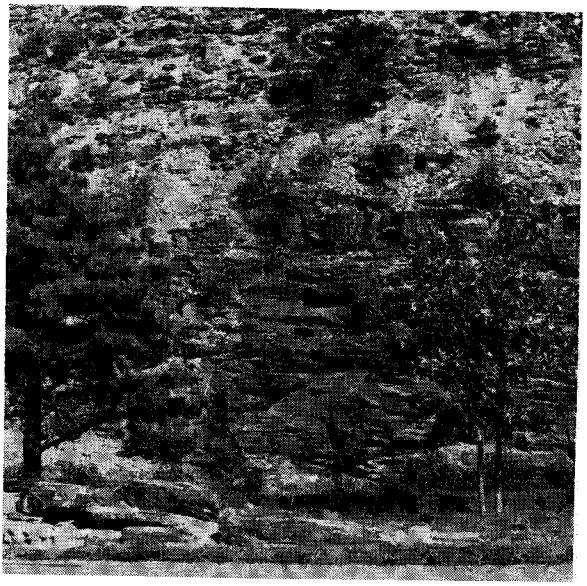

Figure 28. Weverton formation composed of arkosic sandstone, siltstone, and tuffaceous shale, near Horsehead Overlook, Skyline Drive.

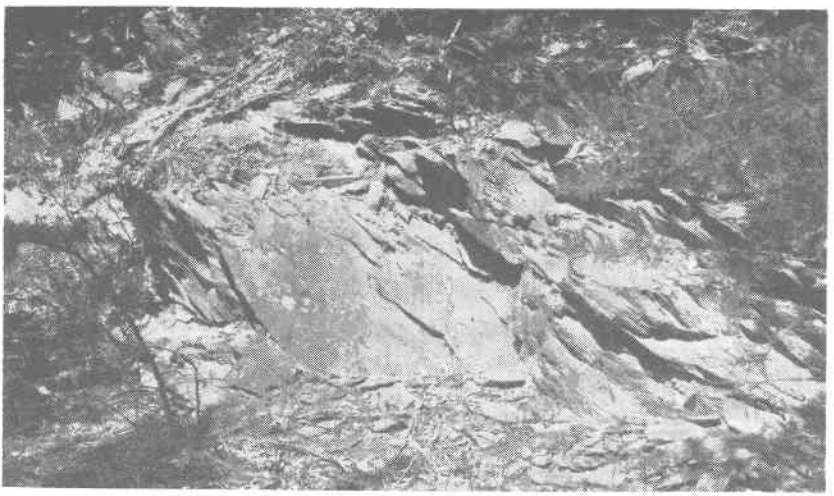

Figure 27. Loudoun formation composed of red slate with green and gray spots, along Madison Run fire road, Shenandoah National Park.

Figure 28. Weverton formation composed of arkosic sandstone, siltstone, and tuffaceous shale, near Horsehead Overlook, Skyline Drive.

WEVERTON FORMATION

Name and Distribution

Sandstone beds exposed on South Mountain near Weverton, Maryland, were named Weverton sandstone by Keith (1894, pp. 329-333). King (1950, p. 17) used the term Weverton formation for a heterogeneous unit of clastic rocks in the Elkton area and divided the formation into lower, middle, and upper members. In Greene County an exposure of Weverton formation, the lower member of King (1950, pp. 18-19), overlies the Loudoun formation along the head of Ivy Creek valley. Good exposures are near Milepost 76 on Skyline Drive, and outcrops also occur at Brown Mountain, Rocky Top, and Horsehead overlooks (Figure 28).

Lithology and Thickness

In Greene County the Weverton formation consists of thin beds of blue quartz conglomerate with iron-oxide cement, sandstones, arkosic sandstones, and intercalated siltstones. Quartz veinlets and quartzitic layers are common. Two prominent joint sets are present, one striking N. 75°-85° W. and the other approximately N. 20°-25° E. Fracture cleavage is roughly parallel to the bedding that has a steep southeasterly dip. The siltstones have an indistinct slaty cleavage. The Weverton formation exposed in Greene County may be more than 500 feet thick; however, local folds and few exposures make it difficult to obtain accurate measurements. No recognizable fossils have been found in the Weverton in Greene County, although King (1950, p. 19) reports indistinct traces of *Scolithus* in the quartzites of the upper member of the Weverton formation.

TRIASSIC SYSTEM

The exposure of Triassic rock along Rapidan River in the eastern part of Madison County represents the southernmost outcrop of the "Potomac Area Triassic" (Roberts, 1928, p. 2). The west margin of the Triassic rocks in Madison County lies along a northeastward-trending line that extends from Liberty Mill on Rapidan River to the bridge where U. S. Highway 15 crosses Crooked Creek at the county line. The contacts along the west margin are characterized by a series of parallel, steeply dipping gravity faults. In all of these the Lynchburg formation on the west is in fault contact with the (downthrown) Triassic rocks on the east. The faults are offset for short distances by northwestward-trending gravity faults that have relative strike-slip movement.

The outcrop area of Triassic rocks south and east of Madison County wedges out southwestward and appears to be faulted out south of Barboursville (Orange County); the east margin of the Triassic outcrop is apparently faulted against the Catoctin formation of the Southwest-Clark mountain uplift. A small wedge of Catoctin-like rock is present east of the Triassic outcrops in the Madison Mills-Woodberry Forest School area, immediately adjacent to Rapidan River. As noted previously, altered Triassic igneous masses and outcrops of Catoctin formation are so similar lithologically that identification is difficult. Altered mafic igneous masses between Triassic clastic rocks are considered Triassic by reason of this association and their calcic plagioclase content. The massive greenstone bodies along Rapidan River northeast of Madison Mills may be Catoctin and appear to have been reconstituted by regional metamorphism. In thin section, they possess minerals and textures characteristic of a regionally metamorphosed rock; the Triassic igneous masses do not contain such characteristics.

SEDIMENTARY ROCKS

The Triassic rocks in Madison County are, for the most part, a heterogeneous series of conglomerates, arkoses, sandstones, graywackes, siltstones and shales. Sedimentation and igneous activity along with faulting took place intermittently during the entire period of formation of Triassic rock.

Conglomeratic units, named "Border Conglomerates" (Roberts, 1928, p. 9), and a type similar to his variety, "Trap Congomerate" (Roberts, 1928, pp. 19-22), are common along the western border faults. The conglomerates occur as discontinuous masses and have the structure of fanglomerates, or masses of heterogeneous material, which were originally deposited in an alluvial fan or apron. The conglomerates are extremely hard and compact, and are dark gray to dark green, and locally are red to brown. Subrounded to angular masses of greenstone, quartz and quartzite fragments, and gneiss and schist gravels, usually somewhat weathered, occur in a hard matrix of finer material of the same composition as the masses. Calcite and quartz veinlets are common.

Excellent exposures of conglomerate are present in Madison County on State Highway 230 north of Madison Mills, north of State Road 671, and in the fields west of U. S. Highway 15 along Great Run. A recently opened, small quarry in conglomerate along State Road 721 (Culpeper County) across Robertson River from Madison County is the best exposure in the area (Figure 29).

Figure 29. Trap-rock phase of Triassic conglomerate in small quarry north of State Road 721 along Robertson River, Culpeper County.

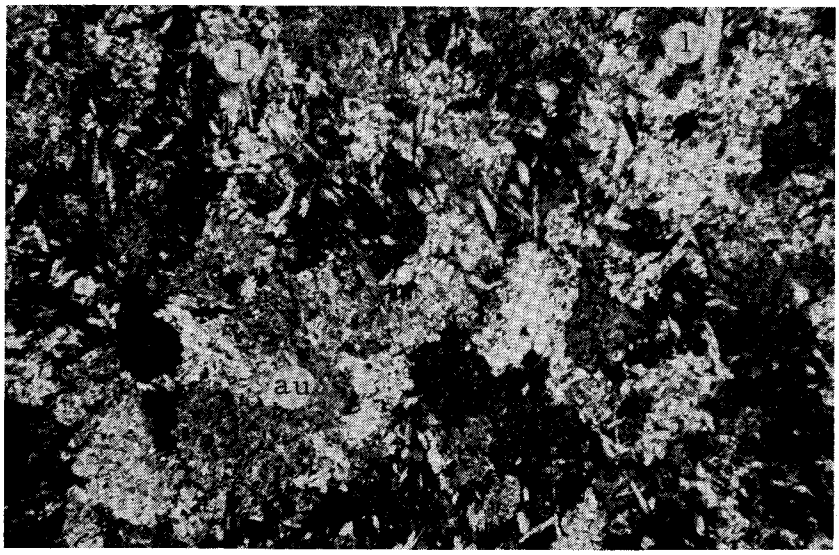

Figure 30. Photomicrograph of altered diabase from Triassic dike (?) north of State Road 623, Madison County. Altered augite (au) and labradorite (l) have subophitic texture. Alteration has produced epidote and chlorite shreds. Crossed nicols. X 55.

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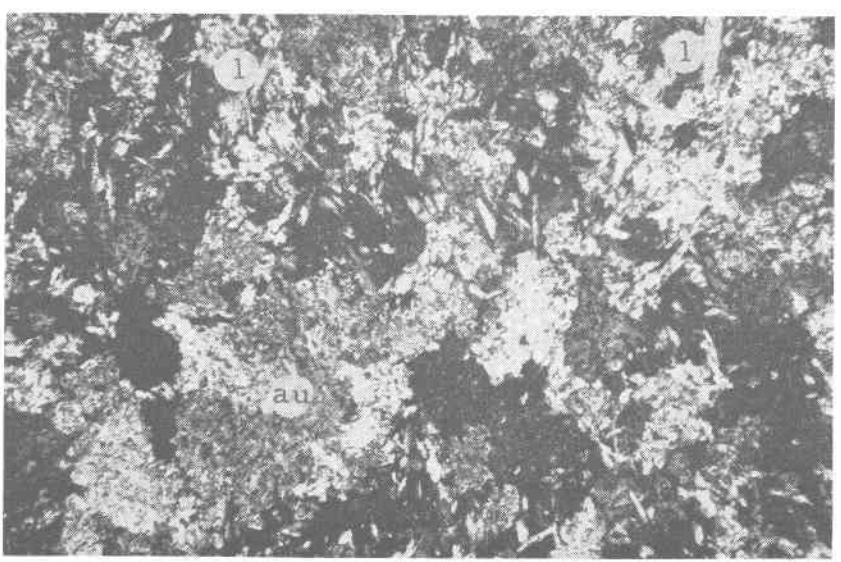

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Red sandstones, arkosic sandstones, graywackes, and red shales are well exposed along Great Run, east of U. S. Highway 15, and near the end of State Road 671. The graywackes contain quartz and feldspar grains in a clayey matrix of phyllite slivers and chips. At the east end of the bridge where State Road 614 crosses Robertson River from Madison County to Culpeper County, a hard, dense, black hornfels is present. Other hornfelsic masses are adjacent to Triassic igneous bodies in Orange County; they were shales that were altered and baked during igneous activity. The altered nature of much of the Triassic sedimentary rock is evident in the exposures near Liberty Mill which crop out in a small bluff on State Highway 231 just south of the bridge over Rapidan River. X-ray examination of this rock, probably an arkosic sandstone that originally contained pyroclastic material, shows approximately 40 percent chlorite, 30 percent muscovite, and 30 percent quartz. Muscovite is from altered potassic feldspars; and although some of the chlorite may have been part of the primary sediment, much appears to be secondary.

FLOWS, DIKES AND SILLS

The Triassic area of Madison County is characterized by numerous igneous bodies. Field relationships indicate some of these bodies are dikes, some are sill-like, and some may have been thin flows. Tabular, dike-like masses of diabase occur in rocks of the Virginia Blue Ridge complex and in the Lynchburg formation. These bodies appear discordant with sedimentary units. Sill-like bodies and amygdaloidal layers, probably thin flows, are concordant with bedding. The dike- and sill-like bodies within Triassic sediments are altered, probably hydrothermally, and they show relic ophitic textures. X-ray and thin sections show chlorite, epidote, plagioclase (An_{50-65}), pyroxene (augite-diopside), small amounts of potassic feldspar, and minor calcite (Figure 30). Good exposures of these altered mafic bodies can be seen on U. S. Highway 15 near the Robertson River bridge, along Great Run both east and west of U. S. Highway 15, and west of State Road 623. A large dike of relatively unaltered gabbro, with subophitic texture and containing about 65 per cent plagioclase (An_{45-60}) and 35 percent clinoenstatite or pigeonite, crops out on the north side of Robertson River in Culpeper County. Rounded residual masses of the same dike are present in Madison County between State Road 614 and the river. Table 5 has approximate modes of several samples from Triassic igneous bodies.

STRUCTURE

The major structural feature in the Greene-Madison county area is the Blue Ridge-Catoctin Mountain anticlinorium (King, 1950, p. 7). This structure contains, in ascending order, the plutonic and metamorphic rocks of the Virginia Blue Ridge complex; the Lynchburg, Mechum River, Swift Run, and Catoctin formations; and the sedimentary rocks of the Chilhowee group. Along the east margin of Madison County the major structural feature is the downfaulted basin of Triassic rock designated by Roberts (1928, pp. 2-3) as the "Southern Part of the Potomac Area." Within these two major structures are minor structural features, including folds, faults, joint systems, and platy and linear structures.

BLUE RIDGE-CATOCTIN MOUNTAIN ANTICLINORIUM

The Precambrian rocks that make up the core of the Blue Ridge-Catoctin Mountain anticlinorium are Lovingston, Marshall, Pedlar, and Robertson River formations and Old Rag granite. Similar rock units are present within the structure from South Mountain, in Pennsylvania, to the southwestern part of Virginia. Unconformably overlying the core rocks of the Virginia Blue Ridge complex are metamorphic units, generally of sedimentary origin, known as the Lynchburg, Mechum River, and Swift Run formations. In the western part of the area these rocks are overlain by, in ascending order, the Catoctin, Loudoun and Weverton formations.

In Madison County the rocks exposed in this structure have an outcrop width of 17 to 19 miles. The granitoid and gneissic rocks of the complex, metamorphosed sediments, and Catoctin and Mechum River formations have an outcrop width of about 13 miles. The Lynchburg formation borders the outcrop of granitoid and gneissic rock on the east and has an outcrop width of 4 to 6 miles. In general, gneissic foliation, schistosity, and cleavage trend northeastward as well as many of the faults, metamorphosed sedimentary units, zones of shearing within the rocks of the complex, fold axes, and zones of structural weakness that controlled the emplacement of dike-like igneous masses in the Precambrian rock. The gneissic structures usually have steep southeasterly dips; although locally, there are reversals of the regional trend, and dips in a northwesterly direction are present. Exposures of schistose rock in the Lovingston and Marshall formations, apparently zones of strong shearing, have a northeasterly trend.

Structural trends in the Swift Run formation appear to parallel those in the overlying Catoctin, indicating that these two formations

behaved as a structural unit during phases of diastrophism. The Catoctin formation, in places, has pronounced cleavage that strikes northeastward and has moderate to steep southeasterly dips. For the most part, foliation closely follows bedding in the Swift Run and layers and flow structures in the Catoctin, but locally it is inclined as much as 30 degrees to the bedding. The Mechum River formation has a northeastward-trending exposure through the center of both Greene and Madison counties. Gooch (1958, p. 570) describes the Mechum River rocks as an infolded mass, and Nelson (1962, p. 24) notes that they occur in a graben belt. This formation appears to be an infaulted and infolded mass of metamorphosed, poorly sorted, sedimentary material that was downfaulted between plutonic and gneissic rocks. These faults, that may have been gravity types, probably developed along or near the crest of the anticlinorium where tensional stresses were active. Later regional compression infolded the sedimentary material and produced thrust faults along the old zones of the gravity faults. Field evidence indicates that the infaulted and infolded sedimentary material was overturned to the northwest because many small isoclinal folds are present.

The Lynchburg formation, also exposed in the anticlinorium, is characterized structurally by a series of ill-defined folds, minor thrust faults, northeastward-trending and steep southeastward-dipping foliation, and minor lineations. The axial planes of the major folds dip steeply to the southeast. Along the west margin of the Lynchburg, relationships between bedding and foliate structures indicate isoclinal folding. Bedding-foliation relationships also indicate that the west margin of the Lynchburg formation is overturned to the northwest.

Thoroughfare Mountain, located about 2 miles southwest of Leon, Madison County, appears to be a synclinal mass of gneissic graywacke breccia of the Lynchburg formation which is overturned to the northwest. A northeastward-trending exposure of Lovingston formation about 0.5 mile northwest of Thoroughfare Mountain indicates a structural high in the underlying Virginia Blue Ridge complex along the northwest margin of the synclinal structure. Small thrust faults are present to the southwest along the same trend. Lost Mountain appears to be a similar, but smaller, synclinal structure containing coarse gneissic graywacke of the Lynchburg formation.

FAULTS IN THE BLUE RIDGE AREA

Faults in the Blue Ridge area, whether parallel or transverse to the structural alignment of the Virginia Blue Ridge complex and over-

lying formations, appear to be high-angle types. Along the east slope of the Blue Ridge a high-angle fault trends northeastward from the headwaters of Rapidan River to the Nethers area on the Rappahannock County line. Near its southwest end this fault bifurcates; the northwest portion passes through Broyles Gap where it divides the Catoctin on the northwest from the Pedlar on the southeast, and the southeast portion passes into a shear zone in the Pedlar and crosses the northwest slope of Doubletop Mountain. To the northeast the main fault extends along the northwest side of Rose River, up Robertson River, through the site of Oldrag Post Office, down Weakley Hollow, across Hughes River north of Nethers, and through Pine Hill Gap into Rappahannock County. In the vicinity of Pine Hill Gap there is a strong slaty and schistose development in the Swift Run formation. A similar shearing of the Swift Run is present along the northwest side of Robertson River just above the junction with Cedar Run. Movement along the fault appears to be essentially of a dip-slip type. Pedlar and Old Rag are present on the upthrown block, and Catoctin is on the downthrown block to the northwest. Near the junction of Robertson River and Cedar Run the northeastward-trending fault crosses, and appears to slightly offset in a left-lateral manner, a northward-trending, high-angle fault. This fault has its south extremity in the Pedlar formation along the northwest slope of Graves Mountain. It extends along the northwest side of Robertson River, up Nigger Run through old Thorofare Mountain School, and terminates in the Catoctin south of the headwaters of Hughes River. Along the extent of the fault, the Old Rag granite on the east has been brought up relative to the Catoctin formation on the west.

Northwestward-trending, high-angle faults, transverse to the structure of the Catoctin, pass across the summit of the Blue Ridge. From northeast to southwest, these faults are present at: 1) Hawksbill Gap, 2) Franklin Cliffs near Fishers Gap (Figure 31), 3) Milam Gap, 4) near Lewis Mountain and 5) about 1 mile southwest of Powell Gap. The faults at Hawksbill Gap, Franklin Cliffs, and Milam Gap on the Madison County side of the Blue Ridge crest are in the Catoctin; the southwest sides are upthrown relative to the northeast sides. This direction of movement is the opposite of that of the northward-trending fault that extends up Nigger Run. The fault near Lewis Mountain (near Milepost 57 on Skyline Drive) is within the Pedlar, Swift Run, and Catoctin formations and has a right-lateral separation in these units. This apparent separation is related either to northwesterly dip in the Swift Run and Catoctin or strike-slip movement along the fault. King (1950, Plate 1) traces this fault northwestward into the Shenandoah

Salient and has named it the Harris Cove fault. The small fault between Mileposts 71 and 72 of the Skyline Drive, southwest of Powell Gap, is within the Catoctin, and it appears that the northeast side of the fault is upthrown. In the Loft Mountain Overlook area (near Milepost 76 on Skyline Drive) it is possible that the Catoctin and Swift Run formations have been thrust northwestward over the Loudoun and Weverton formations, but in this area it is difficult to distinguish between the tuffaceous rocks of the Loudoun and similar lithologies in the Swift Run.

Figure 31. Greenstone flows of Catoctin age at Fishers Gap and Franklin Cliffs. A transverse fault passes through the gap.

FAULTS IN THE PRECAMBRIAN PIEDMONT AREA

Along the east slope of the Blue Ridge where the mountainous terrain merges into the Piedmont are shear zones within the rocks of the complex. Although many of the zones can be traced only for short distances, they are present within all of the gneissic and granitoid units. These zones trend northeastward, generally parallel to the regional alignment, and are from 5 feet to about 0.25 of a mile wide. The shear zones contain schistose and phyllitic structures, developments of biotite and muscovite mica, crushed feldspar masses, and crushed and strained quartz grains; evidence of silicification occurs in the larger zones.

In the area of the Blue Ridge Industrial School, about 1 mile north of Dyke, the Pedlar formation and a small elongate inlier of the Swift Run formation show evidence of shearing and the milling-out of

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the mineral components. The zone extends for about 1 mile in a northeasterly direction, and is 0.25 of a mile wide. Along U. S. Highway 33 between Stanardsville and Lydia, several zones of shearing in the Lovingston and Pedlar formations are exposed in roadcuts. In the area adjacent to, and southwest of, Quinque in Greene County, many small shear zones that have well developed mylonite (recemented finely crushed breccia), and aplitic dikes are in the Lovingston. Northeast of Quinque, the same zone of shearing is in the Westover Church area where sheared Lovingston and migmatitic rock that includes Robertson River formation occur on both sides of the Rapidan River. Numerous small shear zones are shown on Plate 1.

In Madison County, a major zone of shearing in the Pedlar is present in the Buzzard Rocks-Kirtley Mountain area. This zone extends about 3 miles in a northeasterly direction and is about 0.25 mile wide. It appears to be a major tectonic, or deep-seated, fracture along which mineralogic changes in the rocks of the immediate area have taken place. Unakite is present along this zone and also along the crest of Chapman Mountain in what is possibly a northeastward extension of the same shear zone. Zones of northward- to northeastward-trending shearing are present in the German Ridge-Blakey Ridge area and in the Baldtop-Aylor area. The zone that extends along the east side of German Ridge and across Blakey Ridge is about 4 miles long and is present within Lovingston formation and Old Rag granite. In it intense deformation of a rock mass about 0.3 mile wide has developed a schistone and slaty foliation. Quartz-filled fractures are common. To the southeast, a similar zone of schists, phyllites, and slates occurs in the Lovingston and along the border of a small mass of Old Rag granite. Associated with this zone are northeastward-trending quartz veins, that are up to 1 foot thick. One of these veins contains massive pyrite crystals. Along the northwest slope of Dulaney Mountain a northeastward-trending shear zone, about 0.3 mile wide and 2 miles long, occurs in the Lovingston formation. Within this zone, the rocks have schistose and phyllitic structures, and quartz-filled veins are common.

The northwest and southeast margins of the Mechum River formation are believed to be in fault contact with the adjacent rock. Along most of its extent in Greene and Madison counties, the Mechum River is bordered on both sides by Lovingston formation, although for short distances it is in contact with Old Rag-type rocks. At places along the borders, a mixed gneiss, or a migmatitic facies, is present. In Greene County, the southeast margin of the Mechum River is rather well defined and appears to be in fault contact with the Lovingston

formation that is thrust over the Mechum River. Along the northwest margin of the Mechum River formation, contacts with the Lovingston are more poorly defined. In the Celt School area there appears to be a transition zone, 0.5 mile wide, between the Mechum River and Lovingston. The Mechum River is apparently thrust northwestward over the Lovingston. In Madison County structural relationships between the Mechum River and bordering rocks are more complex. The Mechum River formation is in fault contact with the Lovingston and Old Rag in the vicinity of Rapidan River and Neal Mountain. In the Wolftown area a large brecciated and migmatitic inlier of Lovingston occurs in the Mechum River. This inlier probably represents a structural high in the underlying complex. In the Ruth School area and along the northwest flank of Gaar Mountain, evidence of faulting along the contact is present, and apparently the gneissic rock of the Lovingston has been moved northwestward. Along a small transverse fault with right-lateral separation the southeast margin of the Mechum River is offset in the Yager Mountain area. The southeast margin continues to have a faulted contact with Lovingston and migmatitic rock from Gaar Mountain northeastward across Robertson River and into Culpeper County. From the vicinity of Hood to Mitchell Bluff along the Rapidan River the northwest margin of the Mechum River is in contact with a zone of gneiss and migmatite of the Lovingston formation, and it is possible that a fault is present. Along the northwest flank of German Ridge a narrow sliver of Mechum River formation extends for 2 miles in a north-northeasterly direction between Lovingston and Old Rag-type rock. The contact along Burnt Ridge, Hatter Run and Whiteoak Run dips about 65°-70° E. and appears to be a fault zone. The contact of the Mechum River and Lovingston along the southeast slope of Baldtop is apparently offset by a left-lateral fault that is part of a major shear zone. Northeast of the offset the northwest margin of the Mechum River formation continues as a fault contact through the Aylor area to Robertson River near Banco. In the vicinity of Oak Grove Church north of Aylor, a small slice of the Mechum River appears to be offset from the main body. On the southwest slope of Deal Mountain, near the junction of State Road 670 and State Highway 231 north of Robertson River, two northward-trending faults have moved a segment of Mechum River to the north between Lovingston-type rock on the west and a mixed gneiss on the east. North of Banco the northwest margin of the Mechum River formation is in contact with a migmatitic gneiss that grades into a Lovingston-type gneiss to the northeast where the contact is sharper. The contact along the northwest margin of the Mechum River in this area appears to be, in part, fault

controlled, and it is probably marked by a continuous thrust fault from Banco northeastward into Culpeper County.

Exposure of Mechum River formation is very likely controlled by a zone of weakness in the underlying Virginia Blue Ridge complex. After erosion of the complex, and deposition of a thin veneer of clastic sedimentary material during late Precambrian time, gravity faults that resulted from tensional stresses downdropped a wedge of sedimentary material into the underlying complex. Subsequent compressional stresses downfolded the wedge and, in time, caused the gneissic rock of the complex to move northwestward over the sediments and the sediments in turn to slide northwestward over the rocks of the complex that lay along the northwestern border. Such movement explains the thrust nature of the fault contact along both the southeast and northwest margins of the Mechum River. At the time of compressional deformation, the sedimentary rocks were converted into schists, phyllites and other metamorphic rock types.

West of Madison, a gravity-type fault in granite of the Robertson River formation extends northeastward from just north of State Highway 230 to near the junction of State Roads 603 and 638. This fault extends along the southeast valley slope of Whiteoak Run for a distance of approximately 6 miles. The fault zone appears vertical and is characterized by intense shearing; a small amphibolite dike crops out along the southeast side of the fault. Movement along the fault surface appears to have been of a pivotal nature with the greatest amount of dip slippage taking place along the northeast part. The intense shearing may be the result of later compressional forces causing reversal of movement along the fault, a condition similar to that developed along the border faults associated with the Mechum River formation.

Minor faults are present in the Lynchburg formation. Because of the similar lithologies and the presence of foliate structures, the faults and shear zones are difficult to recognize. Major faults do not appear to be present in the Lynchburg within the Greene-Madison area. Two types of minor faults are recognized in this formation: faults of a longitudinal-thrust type, and transverse faults that appear to have strike-slip movement. In Madison County a small thrust fault is along State Road 607 about 0.5 mile north of the ford across Robertson River. The fault zone can be traced for about 2 miles in a northeasterly direction, and there is some evidence in the sheared Lynchburg that it may extend along the northwest side of Thoroughfare Mountain. To the southwest, a small en echelon thrust fault extends from near the electric generating plant on Robertson River (at the end of State Road 702) southwestward to the vicinity of Dark Run southwest of State Road 634.

A small thrust is present along State Highway 230 about 1 mile southeast of Radiant Post Office. The fault extends N. 55° E. for slightly over 1 mile, and to the northeast it appears to merge into an ultramafic dike-like body.

A small transverse fault, located about 3 miles northeast of Madison, strikes approximately N. 20° W. and extends for slightly more than 1 mile in a southeasterly direction from a point just northeast of where U. S. Highway 29 crosses Robertson River. The fault appears to have a left-lateral displacement between the Robertson River and Lynchburg formations. There is another small transverse fault along State Highway 231 near a branch of Beautiful Run, approximately 1 mile south of the old community of Pratt (the road sign designating Pratt is now located at the junction of State Highways 230 and 231). Here indications of minor structural movement are present in a small quarry in the Lynchburg. To the northwest this fault, trending N. 70° W., has caused a small offset in the Lynchburg-Robertson River contact which indicates left-lateral separation.

FAULTS ASSOCIATED WITH TRIASSIC ROCKS

The Triassic igneous and sedimentary rocks in the eastern part of Madison County are separated from the Lynchburg formation of Precambrian age by a zone of gravity faults. Roberts (1928, Plate 1) indicates a single fault along the west boundary of the southern part of the "Potomac area Triassic basin," whereas the present investigation indicates four northeastward-trending gravity-type faults in a zone of Triassic rock which is 3 miles wide (Plate 1). The westernmost fault, with a general trend of N. 35° E. appears to have a dip greater than 45° SE. It separates the Lynchburg formation on the northwest from the downthrown Triassic rock on the southeast. The rather steep dip of the fault plane is indicated by the straight trend of its surface expression. Within Madison County this fault is offset by at least six northwestward-trending transverse faults that have left-lateral separation. The westernmost fault is bordered on the southeast side by a serpentinized greenstone-type rock that is either a dike or sill. Southeast of the western border fault are parallel gravity-type faults that trend N. 30°-50° E. The straight surface traces of these faults indicate that they have a steep dip. They occur either wholly within clastic sedimentary rock or between sedimentary and igneous rocks. All of these strike faults appear to be downthrown on the southeast side. The presence of igneous-appearing rock masses that are quite similar to Catoctin add to the complexity of this area of contact between

the Lynchburg and Triassic rocks. It is entirely possible that these are masses of Catoctin which have been incorporated in the fault movements.

Nine or more northwestward-trending transverse faults are recognized within the Triassic rock of eastern Madison County. Several of these faults appear to extend northwestward, beyond the westernmost strike or border fault, for short distances into the Lynchburg formation. The northeasternmost transverse fault is in the vicinity of the Madison-Culpeper county boundary line and corresponds to a similar fault shown by Roberts (1928, Plate 1). In each instance the transverse faults have a left-lateral separation. Movement along these faults appears to have been entirely of a strike-slip nature.

Undoubtedly, the northeastward-trending gravity faults have been responsible for the downdropped wedge of Triassic rock, and it is probable that the present course of Rapidan River along the east margin of Madison County is in part controlled by the less resistant Triassic material. Similarly, the lower courses of Crooked Run and Robertson River may be structurally controlled by the northwestward-trending transverse fault present in that area.

MAJOR FLEXURES

The flexure of greatest magnitude in the Greene-Madison area is the Blue Ridge-Catoctin Mountain anticlinorium. This structure has been described previously, but some mention should be made of the structures associated with the anticlinorium which apparently owe their origin to folding or flexing of the rock units. Along the northwest flank of the anticlinorium, the rocks overlying the Virginia Blue Ridge complex have a northwest dip. In the Greene-Rockingham boundary area the Swift Run, Catoctin, Loudoun, and Weverton formations have dips that range up to 10° NW. These units along the west flank of the Blue Ridge resemble a corrugated mass that has been tilted to the northwest. In the Big Meadows area to the northeast, the Catoctin appears to be essentially flat lying, whereas farther to the northeast, in the Hawksbill-Stony Man area, the Catoctin has a dip of about 10°-15° SE. In this area the Catoctin appears to be part of a low-dipping, upright flank of an asymmetrical or overturned anticline whose axis is along the northwest slope of the Blue Ridge in Page County.

The axis of a northeastward-trending anticlinal flexure in the Pedlar formation extends from the Greene-Albemarle boundary in the vicinity of Cedarmere on Lynch River northeastward through Brokenback Mountain, Lunt Mountain, and Powell Mountain to near Barnet

Mountain in the vicinity of Kinderhook where it terminates. A similar flexure in the Pedlar, offset slightly to the northwest, extends from the vicinity of Buzzard Rocks and Bluff Mountain (Madison County) northeastward through Fork Mountain and Doubletop Mountain to just northwest of the crest of Old Rag Mountain. Evidence for the structural highs in the Pedlar and Old Rag is in part based on the slight gneissic foliation of the rock, but mainly on the relatively high position of these basement units within the area.

The present field study of gneissic foliation in the Lovingston indicates a broad flexure of gneissic rock, characterized by minor folding of an imbricate nature. Within the Lovingston there is a northeastward-trending exposure of metamorphosed sedimentary rock, the Mechum River formation.

The Lynchburg formation in the eastern part of Greene and Madison counties lies along the east margin of the anticlinorium, and bedding and foliation relationships indicate that the Lynchburg forms a monoclinal or anticlinal structure. The presence of a broad arch in the Lovingston and what appears to be an anticlinal development in the Lynchburg necessitates a structurally depressed area in the Robertson River formation. Several small streams, White Run, Elk Run, and Whiteoak Run, whose courses generally follow the outcrop of the Robertson River might be cited as possible evidence for a depressed zone. Within the Lynchburg formation minor isoclinal folds appear to be prevalent, and one syncline extends along the Lost Mountain-Thoroughfare Mountain trend.

MINOR STRUCTURAL FEATURES

Bedding is clearly evident in the Loudoun and Weverton formations (Figure 28), and in the metasedimentary formations bedding is generally discernible. The various lithologic units of the Swift Run formation have distinct bedding in some places (Figure 23); but where a later foliation has developed, the original rock and bedding character is generally obliterated. In the phyllitic and schistose rocks of the Mechum River and Lynchburg formations bedding is not apparent, but within the coarser clastics, such as graywacke and arkose units, bedding has been accentuated by differential weathering (Figures 15, 16). Cross-bedding is prevalent in the coarse clastic facies of the Lynchburg (Figure 17).

Foliation, here considered as a structural characteristic, is present in the form of cleavage, schistosity and gneissic structure. Cleavage is characterized by closely spaced, parallel, planar surfaces and is generally

dependent upon the parallel alignment of the surfaces of platy minerals. Axial-plane cleavage (often called slaty cleavage) is usually more or less parallel to the axial planes of folds. Cleavage of this type is especially well developed in some of the Catoctin layers. Fracture cleavage is a shear cleavage generally characterized by minor slippage along the cleavage surfaces. In the Mechum River and Lynchburg formations the prevalent schistosity is of this type.

Increase in grain size of the mineral components in schistose rock usually develops an irregular foliation surface, and in phyllites and schists the term schistosity is used in preference to cleavage. The term phyllite is used for fine-grained rocks having schistosity; and schist, for those that are somewhat coarser grained. A well-defined schistosity is prevalent throughout rocks of the Mechum River and Lynchburg formations. The coarser phases of foliation, usually marked by the layering of component minerals, are usually designated gneissic foliation or gneissic structure. Such structure is especially well developed in the Lovingston formation. It is developed to a moderate degree in the Pedlar and Marshall formations, and it is poorly developed in the Old Rag granite and Robertson River formation.

Lineation, sometimes known as linear parallelism or linear structure, is characterized by parallelism of a directional property or structure in rock. Lineation may result from the parallel arrangement of the long axes of crystals, fold axes, the crests of small crinkles on a schistose surface, "stretched" or "rolled" pebbles, and "pencils" or "rods" in gneiss. Pencil structure, which is the thin linear feature formed by the intersection of bedding and cleavage planes, may occur in areas of gneissic rock. Such structure, that has a bearing of approximately N. 40° W. and plunges to the southeast, is in a shear zone between the Pedlar and Lovingston along Conway River about 0.25 mile south of Kinderhook. Along the crest of Blakey Ridge, in the sheared rock of the transition zone between the Lovingston formation and Old Rag (Marshall?) granite, is a prominent pencilling of gneissic rock that has a bearing of N. 30° E. and plunges to the northeast.

In the Mechum River formation the phyllitic units have pronounced small corrugations or crinkles that represent small drag folds. The crests of the folds strike N. 30°-50° E. and generally have a northeast plunge. These small drag folds serve a most useful purpose in determining the tops of beds. An excellent example of such crinkle folds is present on State Road 633 along Swift Run west of Swift Run Church.

Stretched or rolled-out pebbles of blue quartz are present in sheared zones of Lovingston and also in the coarse clastic facies of the Mechum River formation. One area of stretched blue quartz pebbles in the

Lovingston lies along the west and southwest flank of Parker Mountain along State Road 633 in Greene County. The Lovingston formation contains stretched blue quartz grains with a bearing of N. 25° E. along State Road 603 in the vicinity of Roach River. The long axes of the pebbles are parallel to the regional trend of the shear zones and may be used to determine the direction of maximum movement along the shear zones. Stretched or rolled-out blue quartz pebbles are also present in conglomeratic units of the Mechum River formation along South River (Greene County) in the vicinity of Eppards Mill. In this area the bearing of the long axes of the pebbles follows the regional strike of the rock units.

GEOMORPHOLOGY

Greene and Madison counties lie within two physiographic provinces, the Blue Ridge and the Piedmont. The Blue Ridge province extends from the crest of the Blue Ridge Mountains eastward to the foothills where it merges with the Inner Piedmont (Fenneman, 1938, pp. 139-140). Within Greene County the Piedmont slopes gradually eastward from the foothill area to the east margin of the county; there are a few outlying hills, or monadnocks, on the Piedmont surface. Madison County has more extensive foothills, and Triassic sedimentary and igneous rocks are present along the east margin.

Interpretation of the landforms in the area and their geologic development has been the subject of much discussion and writing. Erosion surfaces and their geomorphic development are discussed by King (1950, pp. 52-63), Stose (1940, pp. 46-476), Wright (1934, pp. 1-43), and Johnson (1931, pp. 14-21). These writers have differing opinions concerning the history of erosion, landform development and the number and ages of erosion surfaces developed and preserved. A number of writers have suggested that the Appalachian region in general, and the present Blue Ridge portion in particular, may have been regionally uplifted and reduced by erosion to a peneplain, or "almost-a-plain," at least once and perhaps several times. Peneplain development involves regional uplift followed by a period of erosion that reduces the uplifted region to a nearly flat surface with just enough gradient for streams to flow seaward. Hills, composed of more resistant rock, rising above the gently sloping peneplain surface are known as monadnocks. Renewal of uplift would inaugurate a new cycle of erosion, and the wearing away of the area by streams would develop a newer, and lower, erosion surface. The peneplain developed by the earlier erosion cycle would lie at a higher elevation.

Recognition of such erosion-surface development is possible in the Valley and Ridge province west of the Blue Ridge, but similar recognition of former widespread erosion surfaces in the Blue Ridge and Piedmont is difficult. The summit elevations in the Blue Ridge are too irregular to postulate, without question, the presence of a peneplain, but these upland surfaces may reflect an old erosion surface. Subsequent uplift brought the old erosion surface, the present Blue Ridge, to a higher elevation, and renewed downcutting by streams developed a younger, and lower, erosion surface on the Piedmont. The high knobs or peaks along the crest of the Blue Ridge such as Hightop, Lewis Mountain, Hazeltop, Hawksbill, and Stony Man represent monadnocks on the summit surface. The hills rising above the Piedmont surface, such as Parker Mountain, Bingham Mountain, Gaar Mountain, and Dulaney Mountain, represent monadnocks on the lower and younger Piedmont erosion surface. In general these landforms have resulted from differential weathering and erosion of the various types of bedrock. Also the structure of the rock has had some effect on the characteristics of these forms.

BLUE RIDGE

The crest and east slope of the Blue Ridge are made up of rocks of the Virginia Blue Ridge complex and Swift Run and Catoctin formations. Greenstone caps some of the higher knobs, such as Flattop (elevation about 3,310 feet), Hightop (3,585 feet), Saddleback Mountain (3,400 feet), Blackrock (3,721 feet), Hawksbill (4,049 feet), and Stony Man (4,010 feet). Lewis Mountain (about 3,600 feet), Fork Mountain (3,852 feet), Doubletop Mountain (3,201 feet), and Old Rag Mountain (3,291 feet) are composed of granodiorite or granite. In the southwesternmost corner of Greene County, along the Skyline Drive, Lower Cambrian clastic rocks are present. Most, if not all, of the wind gaps along the crest of the Blue Ridge at some time in the geologic past were water gaps. Prior to the uplift of the Appalachian area, or the regional subsidence of contiguous regions as suggested by Cooper (1961, pp. 6-8), and during the uplift of the Blue Ridge, streams generally had southeasterly courses across the region. The headward development of the Shenandoah River and its tributaries beheaded the upper courses of the southeastward-flowing streams, and their remnant valleys are preserved as wind gaps. Evidence in support of the theory of southeastward-flowing streams of larger magnitude than are now present is the tremendous quantity of stream cobbles, of all lithologic types including Lower Cambrian clastics, which cover the upland surface of the Inner

Piedmont. Part of this gravel veneer may be of colluvial origin, but the degree of sphericity of the gravels and their widespread distribution suggest an alluvial origin.

No great difference in resistance to weathering or erosion between the greenstone and the granitic rock of the Blue Ridge is apparent. The summit areas seem to be equally well developed on both rock types. One phase of the degradational process that deserves special mention is the development of talus and scree on the slopes of the Blue Ridge. These accumulations are best developed along the west slopes of the Blue Ridge in the Lower Cambrian units, but colluvial developments of talus are also present along the east slopes, especially in areas of greenstone. Hack (1960, p. 1878) suggests, "The scree is produced, moved, and weathered by processes active today, although the rates of formation and weathering may have varied in the past." Big Meadows, a relatively flat area of approximately 2 square miles, is situated on the crest of the Blue Ridge between Milam Gap and Fishers Gap. It is suggested that the Big Meadows area is comprised of flat-lying flows of Catoctin age that were uplifted at the time of development of the Blue Ridge-Catoctin Mountain anticlinorium and that the area does not represent the remnant of a former peneplain surface.

Calculated gradients of the east slope of the Blue Ridge are contingent upon the selection of a line, or zone, where the Blue Ridge province merges eastward with the Inner Piedmont. The change in topographic contour interval in the Madison quadrangle is at the 800 foot contour, and, using this as the east margin of the Blue Ridge, the gradients of the east slope in Greene and Madison counties range from 350 feet per mile to 650 feet per mile. These values are higher than the stream gradients noted in the section on Surface Water (Table 6). In the geomorphic development of the slopes, weathering of the greenstones has resulted in the formation of several waterfalls. These are present in South River canyon (Figure 32), along Rose River, in Whiteoak Canyon, along Hughes River, and at the head of Roach River. Associated with the steep gradients along streams is the development of potholes in the greenstone. The east slope of the Blue Ridge, which is somewhat steeper than the west slope, ranges from 6 to 7 miles in width in Madison County, and from 4 to 5 miles in width in Greene County.

It has been contended that the origin of the Blue Ridge as a topographic high and the formation of the wind gaps are dependent upon structural influences. White (1950, pp. 1309-1346) indicated that a border fault along the east margin of the Blue Ridge might be a geologic structure related to the development of the Blue Ridge upland. Weath-

Figure 32. South River Falls, Greene County. Here the South River drops a distance of 70 feet over greenstone of the Catoctin formation.

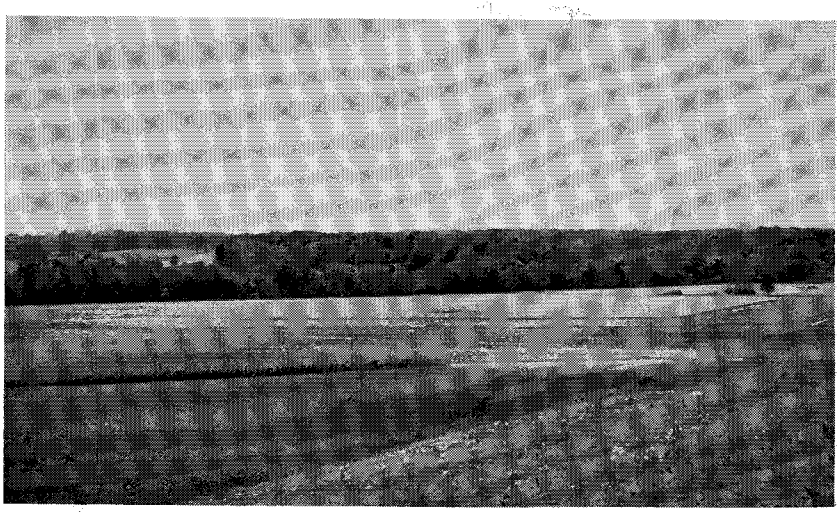

Figure 33. Flood plain of Rapidan River south of Rochelle, Madison County.

Figure 32. South River Falls, Greene County. Here the South River drops a distance of 70 feet over greenstone of the Catoctin formation.

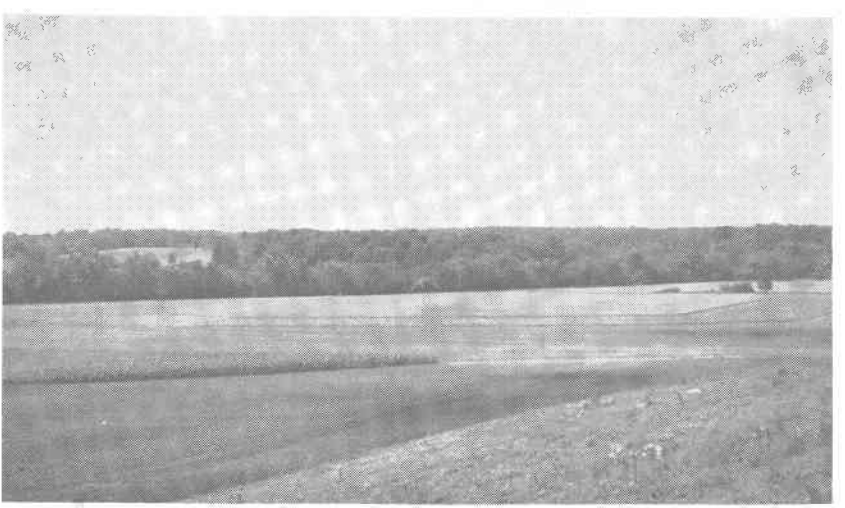

Figure 33. Flood plain of Rapidan River south of Rochelle, Madison County.

ering and erosion, subsequent to faulting, have caused the Blue Ridge front to retreat westward as an escarpment (White, 1950). Such a fault was not found during the present investigation. Immediately west of Old Rag Mountain the location of parts of Rose River, Robertson River, Nigger Run, and Brokenback Run in Madison County probably are related to the presence of faults.

It has also been suggested that some of the gaps in the Blue Ridge within this area developed along faults (Nelson, 1938). An examination of the Swift Run Gap area and of the gaps to the south did not support a fault-control origin for these gaps. North of Swift Run Gap, the wind gaps in the crest of the Blue Ridge, Milam Gap, Fishers Gap, and Hawksbill Gap, appear to be related to gravity faults, although some strike-slip movement may have occurred.

Several origins suggested for the evolution of the east scarp of the Blue Ridge are: 1) faulting, 2) marine erosion contemporaneous with the development of a sea cliff, 3) differential erosion in part controlled by the rocks of the Blue Ridge being more resistant than those of the Piedmont, 4) monoclinal flexing or warping, 5) westward migration of the divide forming the crest of the Blue Ridge, and 6) combinations of these processes. From the present investigation the Blue Ridge is believed to represent a remnant of what must have been a much wider upland area. The early eastward-flowing streams, although initially flowing across the upland surface, had their westernmost extremities captured by the tributaries of the Shenandoah River. These eastward-flowing streams, with steeper gradients than streams flowing westward from the crest of the Blue Ridge, have caused the westward migration of the drainage divide. At the present time the divide of the Blue Ridge appears relatively stable, although the eastward-flowing streams continue to have steeper gradients than the streams flowing westward from the crestal area.

INNER PIEDMONT

The Blue Ridge merges eastward into the Inner Piedmont province; the mountain spurs lessen gradually in elevation. Piedmont elevations range from an arbitrarily chosen 800 feet along the west margin to about 350 feet along the Rapidan River. The gradient of the Piedmont surface from the foothill area to the Rapidan River is about 40 to 50 feet per mile, using the upland surface as a basis for measurement. Stream gradients are lower, generally 10 to 20 feet per mile.

The continuous, unbroken mass of the Blue Ridge is flanked on the east by a number of isolated hills and small mountains. In Greene

County, Parker Mountain has an elevation of 1,440 feet; Bingham Mountain, 1,380 feet; and Goodall Mountain, 1,040 feet. These mountains are, for the most part, composed of the Lovingston formation, although Bingham Mountain has a massive diabase or greenstone dike along its crest and southern flank. Sims Mountain, elevation 880 feet, and Chapman Mountain, elevation 805 feet, consist of a coarse-textured, Old Rag-type granite. In Madison County some of the more conspicuous mountains that are detached from the main Blue Ridge are: Dulaney Mountain, elevation about 1,200 feet, and Deal Mountain, elevation 1,100 feet, both of which are made up of the Lovingston formation; Gaar Mountain at an elevation of 1,300 feet on the south extremity (Yager Mountain); and 1,200 feet at the north end (Beamers Head). The bedrock of Gaar Mountain is a composite of Lovingston formation and Old Rag-type granite. Neal Mountain, elevation 1,120 feet, has a massive amphibolite dike in Old Rag granite.

The Lynchburg formation forms two noticeable monadnocks in Madison County. Lost Mountain, a twin-knobbed hill with its higher elevation at 760 feet, is composed of coarse graywacke. Thoroughfare Mountain has a northeasterly trend and is about 3 miles long and 1.1 miles wide. Its crest (1,224 feet at the highest point) consists of coarse graywacke breccia, that is more resistant to erosion than the surrounding schists and phyllites of the Lynchburg formation.

Aside from the relatively high monadnocks, the relief on the Piedmont surface is low, averaging from 150 feet in the gneissic and granitoid rocks to slightly less than 100 feet on the Lynchburg formation. In the area of Triassic rocks the relief is about the same as that on the Lynchburg, averaging from 80 to 90 feet. The streams flowing across the Piedmont generally have gently sloping valley walls. The major streams have small flood plains that extend back into the marginal zone between the Piedmont and the Blue Ridge. The alluvial material in the upper reaches of the flood plains is chiefly gravel and coarse sand, and the particle size decreases downstream to a fine sand. Along the east margin of Madison County, the Rapidan River has an alluvial flood plain that ranges from 0.3 to 0.6 mile in width (Figure 33). Recent flood plains along the upper Rapidan downstream from Graves Mill and along the lower reaches of Conway River, South River, Swift Run, and Roach River are less extensive than those along the Rapidan to the east. Along Robertson River from Syria to the vicinity of U. S. Highway 29, an extensive flood plain has developed. Just northeast of Madison it is more than 1 mile wide.

Stream terraces are developed along several of the streams in the area. Along Hughes River about 2 miles north of Etlan a conspicuous,

somewhat level, terrace is present about 35 feet above the present flood plain. Remnants of a higher and older dissected terrace occur above this one. The best developments are southeast of Locust Dale and near the junction of Robertson and Rapidan rivers. A dissected terrace of small areal extent borders the Robertson River upstream from its junction with the Rapidan River. Poorly developed terraces are present along the Rapidan River between Liberty Mill and Rapidan Station.

The stream terraces along Robertson and Rapidan rivers appear to represent unmatched forms that developed as lateral cutting combined with down cutting in lowering the stream channels. The terraces along Hughes River near Etlan may be parts of a former large alluvial fan or cone that developed on the downdropped side of a fault block and was consequently dissected. Along Hughes River in the Nethers area a fan development of what appears to be colluvial and alluvial origin is associated with a fault zone.

Gravels of varying lithology which range from 0.1 to 8 inches and are well rounded litter the surface of the Piedmont upland. The presence of gravel on the upland surface indicates that in the development of the Piedmont the streams migrated laterally over wide areas and left portions of their alluvial residue over the broad expanse of the Piedmont slope. The widespread occurrence of gravel may lend support to the concept of the Piedmont as a pediment form, and also indicates that the Blue Ridge front is a scarp formed by erosion with the drainage divide in constant westward migration.

TRIASSIC OUTCROP AREA

The area of outcrop of Triassic rock in eastern Madison County is from 1 to 2 miles wide. There is little difference between the topography of the Lynchburg formation and that on the Triassic rocks. Nevertheless, there is a minor decrease in average relief on the Triassic rocks, less than 20 feet. However, in Culpeper County north of Robertson River, Cedar Mountain, underlain by a conglomerate facies of the Triassic, has an elevation of 833 feet, about 400 feet above its adjacent area. Lithologic changes in the Triassic rocks have little effect on the topography. Areas of Triassic igneous rocks, flows, dikes and sill-like bodies of diabase and greenstone, have slightly higher elevations than areas of Triassic conglomerate, shale, and sandstone. In general during post-Triassic erosion structural control has been minimal. The present northeastward course of the Rapidan River from Liberty Mill to Rapidan Station does suggest some lithologic and structural control by the Triassic rock. The river follows rather closely the trend of the

Triassic formations, and in the vicinity of Madison Mills it is entrenched 60 to 80 feet into the diabasic and greenstone rock. In this area, especially near Madison Mills and in the vicinity of Woodberry Forest School, valley walls are steep and bluff-like features are present.

GEOLOGIC HISTORY

The bedrock of Greene and Madison counties ranges in age from Precambrian through Triassic. Recent alluvial material is present. Within Greene County the bedrock is entirely of Precambrian and Lower Cambrian age. A small area in the southwesternmost part of the county contains Lower Cambrian clastics of the Chilhowee Group. Madison County contains Precambrian, and possibly Lower Cambrian, igneous and metamorphic rock units. Triassic rocks are present along the east margin of the county.

The Virginia Blue Ridge complex contains the oldest rocks in the two-county area. These rocks are, for the most part, of granitoid and gneissic texture and of sialic and intermediate composition. They have undergone several cycles of deformation and alteration. Much of the original complex may have been of terrigenous origin, and may have consisted of arkosic, siliceous, and graywacke-type material. Original sedimentary material may have been transformed into granitoid- and gneissic-appearing rock during a process of granitization. Some of the igneous and gneissic material such as occurs in the Pedlar, Old Rag, and Robertson River rocks may, in part, be of magmatic origin.

A radiometric age determination (Tilton and others, 1958, p. 1473) on the granodiorite gneiss at Mary's Rock (about 0.5 mile south of Thornton's Gap, Page County, Va.) indicated from zircon an age of 1170-1150 million years and from biotite an age of 890-840 million years. Lithologically, the gneiss at Mary's Rock appears to correlate with the Pedlar formation in Greene and Madison counties. (Tilton and others, 1960, p. 4178). Differing age determinations for two minerals within the same rock may be due to an older primary crystallization for the zircon and later metamorphic recrystallization of the biotite. Kulp and Eckelmann (1960, p. 1912) indicate a primary age of 1100 million years, or older, for the basement rock in the Southern Appalachians and also suggest that widespread metamorphism may have affected the Southern Appalachians about 850 million years ago.

The field relationships between these rock units in the Greene-Madison area indicate the following sequence of events. The Lovingston formation was developed first, and the Marshall formation and Old Rag granite were formed partly concurrent with, and partly somewhat

later than, the Lovingston. The Pedlar formation to the west and Robertson River formation to the east formed as a later, transitional phase. This area may well represent the development of what Read (1957, pp. 374-398) has called a granite series in a mobile belt. Somewhat analogous conditions have been found by Brown (1958, p. 17) in the Lynchburg area and by Bloomer (1950, p. 759) in central Virginia.

It is possible that the Precambrian rock units originated about 1,150 million years ago and that they were modified structurally and mineralogically about 850 million years ago. It appears to the writer that these rock units cut broadly across time lines and that their development continued over an extended period of time.

The changes that occurred 850 million years ago were most likely accompanied by processes of deformation, uplift, and erosion. A long period of erosion was accompanied by contemporaneous deposition in a basin that lay to the east of the Greene-Madison area. As erosion lowered the surface of the Precambrian plutonic and metamorphic complex, the onlap of clastic sediments from east to west occurred over part or all of the denuded surface. To the west, in the area of the present Blue Ridge, the relief on the eroded surface may have been 2,000 feet or more, and the coarse clastic sediments of the Swift Run formation were deposited in the form of surface washes, alluvial cones and fans, and local basin and stream-channel fillings. Clastic debris, represented by the Mechum River and Lynchburg formations, spread eastward across the eroded surface of the complex. It may be that the Swift Run, Mechum River and Lynchburg represent time equivalents that were the initial deposits in what is usually referred to as the Appalachian geosyncline. Within the basin of deposition of the Mechum River and Lynchburg formations there may have been local highs in the igneous and metamorphic complex which may have been the source of clastic sedimentary material; these formations contain conglomeratic beds and wedges of coarse graywacke-type clastics. The depositional environment of these sediments may have been in part terrestrial and in part marine. The conglomerate beds and the poorly sorted arkoses and graywackes of the Lynchburg formation are most likely terrestrial; the original clays and silts, that have been changed into phyllites and schists, may have been deposited in a marine environment.

In late Precambrian or early Cambrian time volcanic materials, both flows and pyroclastics, were extruded widely over the region. The Swift Run formation contains thin flows of basaltic rock and beds of tuff and tuff breccia. The Lynchburg formation was indirectly affected by the volcanic activity because it has beds and lenses of graywacke that contain a tuffaceous matrix. Volcanic activity that occurred

during Catoctin time may have continued into early Cambrian time. Basaltic material, that flowed onto the surface from fissures in the basement rocks, has an aggregate thickness of 1,500 feet or more in the Blue Ridge area. The basalts, flow breccias, and tuffaceous accumulations were erupted onto a surface of relief that may have exceeded 1,000 feet in the Blue Ridge area. The abundant greenstone dikes and the numerous amphibolitic and ultramafic dike- and sill-like bodies that are present as either intrusive or metasomatic masses in the Lynchburg formation and underlying basement rock were probably developed at this time.

Flows of Catoctin, which in places lie unconformably on eroded granitoid and gneissic rock, appear to be conformable with the underlying Swift Run formation. Relationships between the Catoctin and the overlying sedimentary rocks of the Chilhowee group are more complex. The only exposures of the lowermost units of the Chilhowee group, the Loudoun and overlying Weverton formations, are those present in the southwest corner of Greene County along the crest of the Blue Ridge. At this locality there appears to be an unconformable relationship between the Catoctin and the Loudoun. King (1950, p. 41) indicates that along the northwest flank of the Blue Ridge, "The northwestward truncation of the Catoctin greenstone and the Swift Run formation, and the southeastward thickening of the Catoctin are interpreted as being due largely to tilting before Cambrian time and to erosion before the Chilhowee group was deposited."

Recent radiometric determinations indicate several periods of deformation and accompanying metamorphism in the Southern Appalachians during the Paleozoic Era (Long and others, 1959, pp. 585-603; and Kulp and Eckelmann 1960, p. 1912). Biotite from the Lynchburg formation on U. S. Highway 460 between Lynchburg and Bedford, Virginia, 5 miles east of its intersection with State Highway 122, was reported to have an apparent age of 370 ± 13 million years (Long and others, 1959, p. 600). Several cycles of regional metamorphism were responsible for textural, structural, and mineralogic changes in the pre-Triassic rocks. The clastic rocks of the Lynchburg formation were metamorphosed into phyllites, schists and gneisses. The clastic rocks of the Mechum River and Swift Run formations were similarly deformed. Greenstones of the Catoctin formation attained their present textural, structural, and mineralogic characteristics during the Paleozoic deformational cycles. Major structures, such as faults in the Precambrian and Lower Cambrian rock, may also have been formed during these cycles. Concurrent with deformation and metamorphism, uplift and erosion undoubtedly occurred in the area, and southeasterly drainage

along the major streams began. Erosion may have been so active during mountain building that the ancient Appalachian Mountains reached only moderate heights.

In the Mesozoic Era, early Triassic time was undoubtedly one of continuous erosion, but by late Triassic time gravity faulting along the east margin of the area had produced basins in which terrestrial sedimentary material accumulated. These sediments are poorly sorted and generally of a coarse clastic nature. Deposition was accompanied by intrusions and flows of basaltic and diabasic material and by the accumulation of pyroclastic debris. Faulting was concurrent with sedimentation and igneous activity. Jurassic and Cretaceous times were characterized by extensive erosion of the area.

The Blue Ridge and Piedmont areas in Greene and Madison counties underwent continued erosion and periodic uplift during the Cenozoic Era. The topography of the ground surface is the result of differential erosion, and this process is still active at the present time. The summit surface of the Blue Ridge may have been formed from an earlier surface during early Tertiary time. Similarly, the present upland Piedmont surface developed during late Tertiary time. The rate of dissection of the Blue Ridge and Piedmont surfaces was probably increased by moderate uplift in late Tertiary or Pleistocene time.

MINERAL RESOURCES

The mineral resources of Greene and Madison counties have received little attention in the published literature. There are a few scattered references to the copper ores of the Blue Ridge and a brief mention has been made of commercial granite possibilities. Recently some attention has been given to the clays and related materials of the northern Virginia counties. References are noted under the individual headings of the mineral materials. Mineral resources of interest, although their economic potential awaits future exploitation, are: the granitic rocks, and especially the variety known as unakite; ultramafic rock locally known as "soapstone"; sand and gravel; sulfide ores of iron and copper (including the "native copper" ores); clays; the water resources which at the present time are of great concern; and the occurrence of titanium minerals in Madison County which insofar as is known is reported for the first time in this bulletin. The U. S. Bureau of Mines Minerals Yearbook for 1960 (Metcalf and others, 1961) notes no mineral production from Greene County and reports only the recovery of unakite near Syria in Madison County. Figure 34 shows the major

occurrences of rocks and minerals of economic interest in Greene and Madison counties.

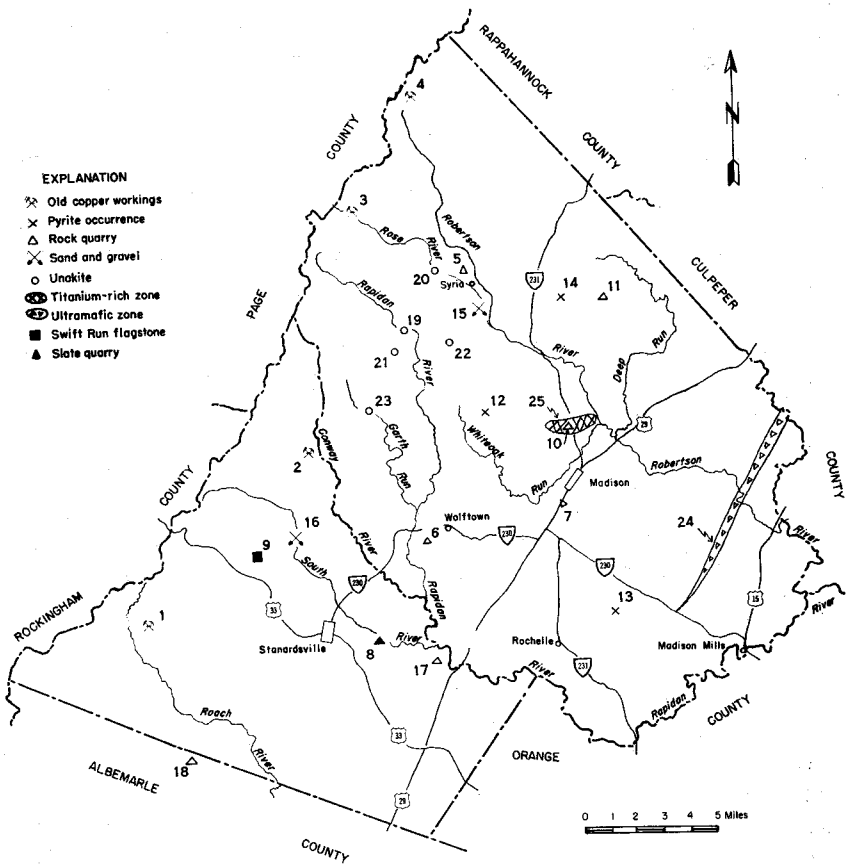

Figure 34. Location map of rock and mineral occurrences in Greene and Madison counties.

GRANITIC ROCKS

Several small quarries have been opened for the production of crushed stone. Specific mention (Steidtmann, 1945) is made of several outcrops of granitic rock and of quarries in granite and other granitoid rock in Greene and Madison counties. Several granitoid rock types are noted by Steidtmann in traverses from Madison to Fishers Gap along the old Gordonsville turnpike (at one time designated as Virginia State Highway 231) and from Stanardsville to Swift Run Gap along U. S. Highway 33. There is an old quarry just west of Madison on the

present State Highway 231 near Whiteoak Run. Petrographic data are given in Steidtmann's bulletin for many of the rock types encountered along these traverses. Two chemical analyses, one for unakite and one for syenite at Milam Gap (near Milepost 53 on Skyline Drive), are listed. Physical test data for coarse-aggregate rock materials from four localities in Madison County and one locality in Greene County were published by the Virginia Department of Highways in 1954. The Department of Highways may be contacted for further data on rock materials in the counties.

Herein are noted several localities where granite or granitoid rock has been produced, usually from a roadside quarry, and generally for use as road ballast and for fill.

Greene County: One-half mile west of Westover Church on State Road 609, to the north of the road along Buckner Run, a coarse-grained, dark-colored, granitoid rock has been quarried locally (Figure 34, No. 17). This rock is similar to a Lovingston-type gneiss with predominant oligoclase-andesine plagioclase and minor amounts of quartz and ferromagnesian minerals.

About 0.5 mile south of Greene County, on State Road 603 in Albemarle County, near the junction with State Road 663, a small quarry was opened in the Lovingston formation (Figure 34, No. 18). The trend of the rock is northeastward into Greene County. This coarse-grained rock that has a granitoid-gneissic texture, contains orthoclase, oligoclase, quartz, and biotite.

Madison County: A quarry has been opened in gneissic rock on Rapidan River just south of State Highway 230, about 1 mile west of Wolftown (Plate 1; Figure 34, No. 6), near Wolftown Mills. The rock from this quarry was used for road material. The quarry face is several hundred feet in length. The rock has a coarse texture, ranges from granitoid to gneissic, and is dark gray where freshly broken. Mineralogically, the rock is composed of orthoclase, albite-oligoclase with some gradations to more calcic plagioclase, and minor amounts of quartz and biotite. This rock may be a border phase of gneiss of the Lovingston formation and granodiorite of the Pedlar type.

About 1 mile northwest of Syria on State Road 649 bordering Rose River, a small quarry was opened in Pedlar-type granodiorite for road material (Plate 1; Figure 34, No. 5). Locally this rock is gneissic.

On State Road 606, about 0.25 mile west of its junction with State Road 604 and about 3 miles northeast of Haywood, the surface of the Robertson River formation has been scraped and the rock opened to a shallow depth (Plate 1; Figure 34, No. 11). The rock that was uncov-

ered in an area of more than 2 acres is reported by local residents to have been used for road material. In this immediate area the granite is weathered to a depth of several feet, and this has made removal of the rock material feasible. The rock is coarsely granitoid and contains quartz, orthoclase and some microcline as common minerals, with minor amounts of hornblende and oligoclase. Several large fresh exposures of this rock may be observed along State Road 606 in the vicinity of the junction with State Road 609. Several inliers of gneissic, biotite-rich rock are incorporated in the granite that grades northwestward into Lovingston formation.

A small quarry in the Robertson River formation is located just to the west of State Road 687 and just north of Hales Store (now marked by a road sign as Pratts) (Plate 1; Figure 34, No. 7). The rock from this quarry, a hornblende granite with a poorly defined gneissic texture, was used locally for road material.

Unakite, a rock associated with the Pedlar formation, is of special interest to gem and rock collectors. It is composed of pink feldspar, green epidote and blue or gray quartz. The rock may be sawed into slabs and small masses, polished, and fashioned into ornamental jewelry. In general, unakite occurs as outcrops of the Pedlar formation, and as stream gravels in the flood plains of the streams that flow southeastward from the Blue Ridge upland. The great bulk of the unakite occurs within the boundaries of the Shenandoah National Park. Because the National Park Service does not permit the removal of rock from the Park area, the stream gravels may be collected from the flood plains of Rose, South, Conway, Robertson, and Rapidan rivers and headwater branches of the Rapidan River (Figure 34, No. 19). The most productive hunting ground seems to be the flood plain and channel of Rose River, upstream from Syria (Figure 34, No. 20).

Several exposures of unakite deserve mention. An outcrop of unakite is present southeast of Fishers Gap within 0.5 mile of the crest of the Blue Ridge beside the trail (the old Gordonsville-New Market turnpike) toward Rose River. A contact between Catoctin formation and granodiorite is within the area adjacent to Hemlock Springs Overlook that is between Mileposts 39 and 40 on Skyline Drive. The granodiorite contains veinlets of epidote and irregular masses of unakite. Several discrete masses of unakitic granodiorite can be seen along Hogcamp Branch and its tributaries at the head of Rose River and just south of Fishers Gap. At the end of State Road 642 in Greene County, unakite is in granodiorite beneath the Swift Run and Catoctin formations. A zone of unakitic granodiorite occurs along the extension of State Road 649 (Madison County) in the Shenandoah National Park

area as the road parallels Rapidan River about 2 miles southeast of the old Hoover camp (Figure 34, No. 21). Unakite can be seen in scattered boulders along the road and in the bed of Rapidan River. Several outcrops of unakite can be found along State Road 649 in Madison County in the gap of Chapman Mountain near the junction of the fire road to Blakey Ridge lookout tower (Figure 34, No. 22). A vein of poor-grade unakite, 6 to 8 inches thick, can be seen in a road cut on the extension of State Road 665 near the junction with State Road 615 in Madison County. This occurrence is about 1.5 miles southwest of Graves Mill and is on Garth Run (Figure 34, No. 23). Along Staunton River, for a distance of about 1 mile above its junction with Rapidan River, unakite gravels can be found, and some exposures of unakite occur along the valley walls.

The value of unakite recovered from Madison County is noted as $25.00 in 1960 (Metcalf and others, 1961, p. 1071). This figure may be unrealistic as it is probable that much unakite has been recovered from the area, and no record is available of its sale value. Another interesting geologic consideration that may be of value in the search for unakite (outside the National Park boundaries, of course), is that the better grade unakite occurs in close proximity to the overlying Catoctin formation, generally within 100 feet of the "greenstone-granodiorite" contact. The unakite localities on Chapman Mountain and on Garth Run are the only outcrops that seem to be some distance from the Catoctin formation. Possibly these outctops were directly beneath the Catoctin formation that has been eroded away.

FLAGSTONE

In Greene County, on State Road 634 about 1 mile north of Lydia, the Swift Run formation has been quarried for local use as flagstone (Plate 1; Figure 34, No. 9). In this area the Swift Run occurs as a medium-grained phyllite or schist, composed essentially of tuffaceous material (Figure 23). A fracture cleavage that has a strike of N. 50° E. and a dip of 15° NE. has developed nearly parallel to bedding. Within the exposed phyllite are sandy or gritty layers that have a quartzitic texture. Slabs of rock measuring 1 to 3 feet on a side and from 1 to 4 inches thick have been removed from the quarry and have been used locally as a paving stone or flagstone. Other areas where the Swift Run may have similar structural features that would make the rock suitable for flagstone or paving stone are: 1) on State Road 638 in Greene County in the gap of Turkey Ridge; 2) along the extension of State Road 636 in Greene County about 1.5 miles from the junction of

State Road 636 with U. S. Highway 33; and 3) along State Road 632 in Greene County about 2 miles west of Bacon Hollow.

Local inhabitants report an old slate (?) quarry on the north bank of South River about 0.25 mile upstream from Eppards Mill (Greene County) (Plate 1; Figure 34, No. 8). At this location there is an overgrown cut in phyllites of the Mechum River formation that may have been the source of rock slabs or flagstones for local use.

ULTRAMAFIC ROCKS AND "SOAPSTONE"

The main mass of an altered ultramafic rock extends from State Highway 230 near Radiant Post Office northeastward for about 9 miles to Crooked Run and continues northeastward into Culpeper County (Plate 1; Figure 34, No. 24). Outcrops range from 1,000 to 2,000 feet in width. The rock is composed essentially of chlorite, tremolite, and actinolite and has minor amounts of feldspar. Smaller dike-like masses of similar rock are found adjacent to the main outcrop and lie to the southeast and also along an extension of the main body to the southwest. This rock has been locally worked for dimension stone or paving stone and has been called "soapstone." There are some notable differences between this "soapstone" and the soapstone near Schuyler. In general, the local rock appears darker and contains larger amounts of feldspar and some quartz. Variations in color and texture occur within short distances. According to local information, this rock was quarried near the communities of Twymans Mill, Achsah, and old Fordville. Quarried and dressed blocks of this rock are around the courthouse yard in Madison and in the walks of some of the older homes in Madison.

SAND AND GRAVEL

There are numerous occurrences of sand and gravel adjacent to streams and their flood plains in Greene and Madison counties. Upland terrace deposits are possibly a major source of sand and gravel.

An area in Greene County that may contain a large quantity of gravel and some sand (Figure 34, No. 16) is in the vicinity of McMullen and the South River Methodist Church. The area is traversed by State Roads 637 and 638. The flood plain of South River, for a distance of 3 miles along the river and for a width of about 0.5 mile, is covered with a sand and gravel veneer that in some places extends to a depth of at least 10 feet. The gravel at the surface ranges in size from 0.08 inch to more than 20 inches in diameter; admixed with this gravel is sand-size material, mainly quartz sand. The occurrence at McMullen may be the direct result of flood action spreading the waters of South

River over a wide area in this vicinity. With a decrease in velocity of stream current the larger rock particles drop out and gravel begins to accumulate. As stream velocity decreases further, the finer particles settle and mix with the gravel. The gravel generally is composed of granitoid and gneissic rock types and a small quantity of greenstone. A few quartzite gravels are probably derived from the Lower Cambrian rocks.

In Madison County sand and gravel that has been utilized is present in the flood plain at the junction of Robertson and Rose rivers about 1 mile southeast of Syria (Figure 34, No. 15). The gravel seems to be generally of a smaller size than that noted at McMullen in Greene County and there may be a greater quantity of sand available. The Robertson-Rose river flood plain is some 2 miles long and about 0.5 mile wide and is wholly underlain by workable sand and gravel deposits. As at McMullen, the bulk of the gravel is granitoid and gneissic rock with small quantities of unakite and a moderate amount of greenstone-type material.

The flood plain of the Rapidan River from Graves Mill southward to the vicinity of Hood is composed of sand and gravel in quantity, and could serve as a source of these materials. Southeast of Hood, and along the Rapidan to where it leaves Madison County east of Madison Mills, the stream bed alternates between restricted channel ways and broad sandy and silty flood plains. These stream deposits are mainly composed of finer sized materials and would not, in general, be suitable for workable sand or gravel deposits.

The upland terraces, especially along the lower reaches of Hughes, Robertson, and Rapidan rivers, contain sand and gravel deposits. Although these deposits are usually some distance away from the streams, which makes washing of the sands and gravels difficult and expensive, they should not be overlooked as potential sources of these materials.

SULFIDE ORES

Three occurrences of pyrite, all in Madison County, are worthy of mention. One occurrence of pyrite that has evidently excited interest in the past is at an old mine located about 1 mile southwest of Good Hope Church and about 0.5 mile south of State Road 621 (Plate 1; Figure 34, No. 13) on a branch of Beautiful Run and within the phyllites of the Lynchburg formation. The local inhabitants indicate that the prospect was first opened during World War I; exploration ceased after the war, and later, during 1950, an attempt was made to reopen the old shaft. An examination of the ground indicates that two shafts

were put down, and one water-filled shaft could be seen during a visit to the prospect in 1960. The small size of the dumps indicates that the shafts could not be very deep, probably not over 25 feet, and that there has not been any extensive workings from the shaft bottoms. As it was impossible to enter the pits, the only pyrite observed was that in the dump material. The small pyrite masses were oxidized and hydrated to limonite, and only scattered, small fragments of fresh pyrite were present. The shafts were sunk in and along a northeastward-trending quartz vein that pinches and swells along strike and averages 1 foot in thickness. The quartz vein is about 400 to 500 feet southeast of a large amphibolite dike, and both may be emplaced along a major shear zone. Interestingly enough, similar quartz veins, some of which are associated with amphibolite, do not contain pyrite. No minerals other than pyrite and limonite were found in the prospect area, and the economic potential of this occurrence appears negligible.

Pyrite is located about 0.5 mile from the end of State Road 651 in Madison County, on the property of David M. Alger (Plate 1; Figure 34, No. 12). The pyrite occurrence may be visited by following a trail up Blakey Ridge past the house on the Alger property for a distance of about 0.25 mile. From this point the prospect pit is reached by going southwestward along the slope of the mountain. The rock of the area is an intensively sheared complex of Lovingston formation, Marshall formation and Old Rag granite. A fault with essentially strike-slip movement has been responsible for the sheared nature of the rock in the immediate area and also along the southeast slope of Blakey Ridge. The strike of the fault changes from north to northeast in the vicinity of the pyrite occurrence.

The pyrite occurs as large clusters of fresh crystals, about 0.25 inch on a side, within a white, glassy quartz vein. The vein has a strike of N. 40° E., and a dip of 70° SE. and averages from 2 to 3 feet in thickness. Associated with the pyrite are small stringers of hard, gray hematite (specularite). The vein quartz is unlike the blue quartz that is common to the granite and gneiss of the country rock and may be younger in age. The emplacement of the quartz vein and its pyrite mineralization was seemingly structurally controlled by the fault zone. An examination of several small streams draining the Blakey Ridge area showed pyrite grains in the alluvial material of the stream beds. It may be that there is additional pyrite localized along the trend of the fault.

Limonite pseudomorphs after pyrite occur along a low ridge that parallels State Road 641 in Madison County about 0.5 mile southwest of Duet (Figure 34, No. 14). The phyllite and schist in this locality

are in a northeastward-trending, narrow, infolded and infaulted outcrop of Mechum River formation. On the surface of the ground along the crest of a small ridge about 300 yards east of State Road 641 can be found many cubes of limonite that range from 0.13 to 1 inch on a side. The limonite cubes are pseudomorphic replacements of pyrite crystals and have weathered from the underlying rock. An examination of the phyllite and schist indicates that the pyrite occurs in thin quartz veinlets in these rocks, and minute quartz crystals can be seen in small vugs and openings in the rock mass. As the pyrite crystals weather out of the rock, the cubical molds are preserved in the quartz matrix. Fresh pyrite is rare and disseminated in the exposed parent rock; the limonite pseudomorphs are common and have striations on the crystal faces. This area is the only exposure of the Mechum River formation that has been found to contain this type of pyrite occurrence.

COPPER ORES

The occurrence of copper minerals in the Catoctin formation of the Blue Ridge region in northern Virginia has been known for a long time. Since the earliest settlement of this region native copper and copper sulfide minerals in greenstones of the Catoctin formation have aroused interest, not only among the local inhabitants but among mining operators and speculators throughout the country. From what can be learned through published material on the Blue Ridge copper ores and from conversations with the older inhabitants of the Greene-Madison county area, it would appear that the mining of copper ores in this area was not a profitable venture. W. B. Rogers (1884, reprint, p. 134) and Keith (1894, p. 309) in their reports mention the occurrence of these ores. Watson (1907, pp. 503-511) notes some of the individual prospects and mines that were in operation. Some of the data in Watson's report are found in Phalen's bulletin (1906, pp. 140-145). More recently, Brophy (1960, p. 1325) discusses the modes of occurrence and genesis of copper mineralization in the greenstones.

From the present field investigation of the old copper workings in the area, the writer concludes that the copper mineralization in the Catoctin formation is generally restricted to the lower part of the greenstone sequence, usually within a few hundred feet above the contact with the underlying granitoid rock of the Virginia Blue Ridge complex. The copper minerals are disseminated in the greenstones and also occur in local pods, or in small veinlets or stringers associated with gash fractures in flows and feeder dikes. It is further concluded that the bulk of the copper mineralization occurs as a primary distribution in

the Catoctin and that low-grade regional metamorphism and the supergene processes of downward-moving meteoric waters recrystallized and reconcentrated local accumulations of copper minerals. Weed (1911, pp. 15-16) and Brophy (1960, p. 1325) have commented on the role of epidotization and serpentinization in the concentration of the copper minerals, and their views are substantiated by the present investigation. The volume changes induced in the basalt flows by serpentinization and the minor openings formed by regional metamorphism, together, developed a structural framework for the concentration of copper minerals, and the epidotization processes undoubtedly facilitated the redistribution of these minerals in the fractured rock.

Few openings or mine workings available for study were found. Specimens of the following copper-bearing minerals, native copper (Cu), bornite (Cu_5FeS_4), chalcopyrite ($CuFeS_2$), covellite (CuS), cuprite (Cu_2O), malachite ($CuCO_3 . Cu(OH)_2$), and azurite ($2 CuCO_2 . Cu(OH)_2$) were uncovered during a close examination of the old dumps, mine workings, and the rock adjacent to the old workings. Closely associated gangue minerals found were quartz, epidote, feldspar, and serpentine.

The copper occurrences visited during the course of the present investigation are briefly discussed below. Reports by Weed (1911, pp. 107-115) include information obtained at the time of active operation of several mines in Madison and Greene counties and have detailed data concerning mineralogy and extent of mine workings.

Hightop Mine: The Hightop mine in Greene County (Plate 1; Figure 34, No. 1) can be reached via part of the Roach Gap fire road that crosses Skyline Drive about 0.3 mile north of Milepost 69. The road intersects State Road 626. The old mine is located on the south side of Hightop and can be reached from an unimproved road that leaves the Roach Gap fire road near the old Hightop mission. The old workings may be found by locating remnants of the concrete base of the draw works (Figure 35); the openings, shaft, and dump are to the south, downslope from the crest of the ridge. The openings are located in the base of a basalt flow and in a schistose and slaty facies of the basalt. The rock is characterized by the presence of amygdules and epidote-filled vesicules. The mine workings evidently consisted of stripped basalt ledges, an open cut, and a shaft reported by Weed (1911) to have been 80 feet deep. Downslope and to the north and south of the shaft collar are indications of trenching and open-pit work. Copper minerals found on the dump are bornite, chalcopyrite, cuprite, and small grains of native copper. Small quantities of covellite, azurite, and malachite are also present. The ore minerals are associated with milky

quartz lenses, and some orthoclase feldspar is present with quartz. Epidotized masses of altered brecciated basalt are common. Evidently the mine was in operation up to about 1906 when an explosion in the powder magazine destroyed the mine buildings, and as a result the operation closed down. An unsuccessful attempt was made in 1944 to reopen the mine.

Figure 35. Site of old Hightop copper mine on Hightop, Greene County. Ring bolt for headframe (at left) is in outcrop of Catoctin formation.

The Tunnel Tract or Sims operation: This abandoned operation is about 1 mile northwest of Fletcher on State Road 667 (Plate 1; Figure 34, No. 2). The old workings may be visited by following a footpath westward from the store to the vicinity of the old cuts. This may be the property described by Weed (1911, p. 113) as the Piedmont Copper Company's property and also as the Sims property and the following notation is made:

> "The mine workings and buildings are about 3,000 feet above sea level and 2,000 feet above the valley. The mineral belt descends the mountain toward the southwest and ascends it to the northeast, traversing the mountain top obliquely 500 feet above the mine, and thence gradually descends, reaching the foothills at Conway River, 20 miles from its starting point."

Another name used by the local people for this old operation is "The Bootens Gap mine." There is evidence of an old open trench and probably what was an adit in the schistose basalt along a shear zone or joint that trends N. 70° E. near the 1,200 foot elevation. No evidence of a shaft was found. The workings are within 100 feet of the base of

quartz lenses, and some orthoclase feldspar is present with quartz. Epidotized masses of altered brecciated basalt are common. Evidently the mine was in operation up to about 1906 when an explosion in the powder magazine destroyed the mine buildings, and as a result the operation closed down. An unsuccessful attempt was made in 1944 to reopen the mine.

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the Catoctin and above an exposure of phyllite and quartzose rock of the Swift Run formation. Small quartz veinlets and pods occur in the sheared and brecciated basalt, and epidotized feldspar is common. Crystals of chalcopyrite and pyrite were scattered within the quartz veinlets. No other copper minerals were found.

Dark Hollow mine: This mine in Madison County was reported by Weed (1911) to be a well-developed operation. It was located at the headwaters of Rose River about 1 mile southwest of Fishers Gap (it was mistakenly placed at Milam Gap by Weed) and about 0.5 mile north of the switchbacks in the old Gordonsville-New Market turnpike (Plate 1; Figure 34, No. 3). A well-marked Park Service trail is adjacent to the old mine workings.

Remnants of the old workings include a caved adit, several partially filled open pits or trenches, and a dump, well overgrown with brush and trees, at the mouth of the old adit. Concrete bases for mine equipment such as draw works and boiler are present. The operation was opened before the Civil War, was dormant for many years, and was reopened by the Blue Ridge Copper Company about 1902 (Weed, 1911, pp. 107-109). He reported that three shafts were sunk, that about 70 feet of drift work was opened, and that some ore was shipped. Data are not available as to the tenor of the ore and whether operations were profitable.

It is interesting to note that the Dark Hollow operations are located about 100 feet vertically above a Catoctin-Pedlar contact. The altered basalt is schistose and slaty in this immediate area and is traversed by several sets of joints. The joints are filled with milky quartz and epidotized brecciated rock. Vein epidote and unakite are common in this area. A few scattered grains of chalcopyrite were the only indication of copper mineralization. Trenching of the old dump uncovered a few specimens of chalcopyrite, cuprite, and malachite and a few grains of native copper.

Stony Man mine: The Stony Man mine began operations in the 1850's (Weed, 1911, pp. 109-111). Little can be seen of what may have been fairly extensive operations, although from the literature one gathers that this mine never reached the size or activity of the Dark Hollow mine or the Hightop mine. Remnants of the old operations are near the crest of Stony Man, and Stop Number 26 on the Stony Man Park Service nature trail is designated as the copper mine area (Plate 1; Figure 34, No. 4).

The Catoctin formation on Stony Man is a massive flow with an amygdaloidal facies and layers of slaty tuffs. The west face of Stony

Man has steep cliffs, and immediately under the cliffs, about 800 feet lower in elevation, is a thin wedge of Swift Run formation that overlies granodiorite. The occurrence of copper mineralization is not as close to the basalt-granodiorite contact in this area as that of Dark Hollow, and the degree of epidotization in the greenstone is not as extensive. However, the basaltic rock appears well fractured and has at least two well-defined joint sets, one with a strike of N. 20° E. and a steep southeasterly dip and another with a strike of N. 60° W. and a steep northeasterly dip. Joints and cleavage surfaces contain veinlets and lenses of quartz and secondary epidote. Malachite-stained rock surfaces next to quartz-filled fractures are present in the area of the old mine.

About 0.5 mile to the west of the Stony Man mine and 0.25 mile north of Skyland along the Appalachian Trail is the site of an old furnace known as Furnace Springs. It is reported by the local inhabitants that ores from Stony Man mine and from other small operations in the area were smelted in the furnace at this site. Slag is present in quantity in the immediate vicinity of the old furnace site.

There is definite evidence of copper mineralization in the Catoctin formation of Madison and Greene counties. It should be noted here that old copper mines are in Page, Warren, and Rappahannock counties as well. Even though the deposits in the Catoctin were mined in the past, future exploitation, if any, would be quite limited. A close inspection of the Catoctin units near the contact with the underlying granodiorite and Swift Run formation usually will indicate milky quartz veinlets and stringers that contain a few scattered copper sulfide minerals. Native copper is uncommon, and it is the opinion of the writer that much of the so-called "native copper" in reality was a minor accumulation of iron and copper sulfides.

CLAYS

The clays in Greene and Madison counties that may have economic potential can be classified as follows: 1) residual clays overlying the granitoid and gneissic rocks of the Virginia Blue Ridge complex; 2) clays associated with the schistose and phyllitic rock of the Mechum River and Lynchburg formations; 3) transported clays found in terraces and flood plains; and 4) residual clays derived from the Triassic sedimentary rocks. A report on the analyses of clays and shales of the northern counties of Virginia (Calver and others, 1961) includes one analysis of clay from Greene County and four analyses of clay from Madison County. The residual clays that overlie the granitoid and gneissic rocks of the complex have a large areal extent and may extend

in depth below the surface as much as 10 to 15 feet. These clays for the most part have been derived from weathering of the underlying rock. In the foothill region along the east slope of the Blue Ridge the residual clays are intercalated with colluvial clayey material that has resulted from the mass-wasting processes along the mountain slopes, and it is difficult to determine how much of the clay is residual and how much is of a transported nature. These clays are gritty, and contain small, angular rock fragments and angular grains of quartz.

An analysis of an alluvial clay from the flood plain of Robertson River indicates that it might be suitable in brick or tile manufacture (Calver and others, 1961, p. 93, sample R-1708). At the plant of the Webster Brick Company, Inc., which is 1 mile south of Liberty Mill, Orange County, common and face bricks are manufactured from shale of Triassic age. Mr. O. R. Sluss, plant manager, made available some analytic data on the shale. The shale is reported to be a micaceous illitic siltstone that contains some chlorite, minor amounts of quartz, tourmaline and rutile, and questionable calcite. The clay-mineral fraction is given as about 50 percent illite and 10 percent kaolinite. Calver and others (1961, p. 98) report analytical data on the Triassic shale from this locality. An examination of the open pit at the Webster plant indicates that the material recovered is a massive, well-consolidated siltstone. Rock of similar lithology occurs with the Triassic shales of eastern Madison County, and it is probable that these siltstones and shales have economic possibilities similar to those in Orange County.

In examining the surface clays associated with the Triassic sedimentary and igneous outcrops, two occurrences of white clay were found. One occurrence is in a cut along the northwest side of State Road 620 in Madison County, about 0.75 mile southwest of the junction of State Road 620 and State Highway 230. Approximately 10 feet of the white clay is exposed in the cut. The clay appears to be a residual accumulation over a tuffaceous layer of the Triassic sequence. The clay is probably kaolinite and is decidedly plastic as found in place. A similar occurrence of white clay is located along the east side of U. S. Highway 15 just south of its junction with State Road 614 at the Locust Dale store. Here, the clay may be residual and the weathered product of a tuffaceous bed of the Triassic rocks.

TITANIUM-BEARING MINERALS

Megascopic and microscopic examination of several varieties of granitoid and gneissic rocks of the Virginia Blue Ridge complex shows

the presence of titanium-bearing minerals. Ilmenite ($FeTiO_3$); its alteration product, leucoxene; sphene ($CaTiSiO_5$); and small grains of rutile (TiO_2) are prominent in certain border zones of the Lovingston formation. Although all of the granitoid and gneissic rocks of the complex contain small scattered grains of ilmenite and sphene, the outcrop of Lovingston rock on State Highway 231 about 2 miles northeast of Madison contains a concentration of these minerals that is above the usual amount. A zone that is approximately 3.5 miles in length trends N. 70° E. from the southeast slope of Yager Mountain (Plate 1) eastward across Robertson River to an area near the junction of State Roads 638 and 603 (Figure 34, No. 25). This titanium-rich rock has its western extent within the Lovingston formation and its central and eastern parts within the Robertson River formation. The country rock that contains the titanium minerals appears to be a border facies. Local concentrations of ilmenite grains, up to 0.04 inch, make up perhaps one percent of the rock. Flattened masses of sphene, up to approximately 0.4 inch in length, are especially noticeable in a small opening or quarry on the west side of State Highway 231 about 2 miles north of Madison (Plate 1; Figure 34, No. 10). Under the microscope, ilmenite grains were noted to have coronas of leucoxene and sphene (Figures 4, 5). The Lovingston formation along State Road 600 about 1 mile southeast of Syria also contains an unusual amount of ilmenite and sphene. The extent of this zone is unknown as the titanium minerals are for the most part microscopic and can be recognized generally in thin section only. From present investigation of the titanium-bearing rocks there is little ilmenite that might offer commercial possibilities. The widespread presence of these minerals, the generally prevalent nature of purplish quartz in granitoid and gneissic rock, and the occurrence of massive veins of blue or purplish quartz that is evidence of finely divided titanium minerals, indicate that the element, titanium, played a major role in the mineralization of some of the rocks of the Virginia Blue Ridge complex.

MISCELLANEOUS MINERALS

Hematite (Fe_2O_3) was found in small quantities at several localities in the area. At the base of South River Falls the Catoctin is an intensively brecciated flow that contains numerous quartz veins and thin (0.2 inch) stringers of fresh and unweathered hematite with metallic luster. Quartz veins and associated 2-inch layers of hematite and ocher (a term applied to earthy forms of hematite and limonite) in phyllite and schist of the Mechum River formation are in the road cuts along U. S. Highway 33 and State Road 633 west and southwest of Quinque,

Greene County. Similar occurrences are present in the road cuts along Deep Run and Quarter Creek. In Madison County along State Road 603 north of Duet in the contact zone of the Lovingston and the Mechum River formations, are numerous hematitic and limonitic stringers and lenses. For the most part these ocherous masses are thin and mixed with clay. Metallic hematite stringers, from 0.2 to 1 inch wide, are in a massive greenstone dike- or sill-like mass of Triassic age that crops out about 1 mile upstream from where U. S. Highway 15 crosses Great Run in Madison County. This occurrence of hematite is very similar to that noted in the Catoctin at the base of South River Falls.

Magnetite (Fe_3O_4) is a common accessory mineral in the Catoctin greenstones and occurs in quantities that will deflect a compass needle. This is especially noted in the Hazeltop area on the Madison-Page county line. Concentrations of magnetite sand with some ilmenite are present in the alluvial sands and silts along several of the streams that drain the Catoctin terrain. One such locality in Greene County is the flood plain of Roach River where it is crossed by State Road 648. Magnetite sand with grains 0.01 inch in diameter is common along the Roach River in this vicinity and can readily be recognized by the black color of the sandy stream bed. Magnetite sand is also present in noticeable quantity along the South River north of Stanardsville and in the flood plain of the Conway River.

An occurrence of asbestos-form material is associated with the hematite and ocher along State Road 603 in Madison County about 2 miles north of Duet. The asbestos-like fibers occur in a shear zone approximately 5 feet wide which is in the contact zone between Lovingston and Mechum River formations. A microscopic examination of the fibers indicated that the mineral form is that of anthophyllite, (Mg, Fe) SiO_3, although other asbestos-like minerals may be present. The altered and bleached nature of the occurrence indicates a hydrothermal alteration of an amphibolite dike within the shear zone.

The conglomeratic facies of the Triassic sedimentary rocks is utilized for crushed stone and road grade fill in several Virginia localities. In the Culpeper area Roberts (1928, pp. 125-126) cites several localities where conglomerate has been quarried. The term "trap conglomerate" is used by Roberts (1928, pp. 19-22) to describe the particular conglomeratic facies of the Triassic found in the eastern part of Madison County. A small quarry was opened in this rock by the side of State Road 721 in Culpeper County, just across Robertson River from Madison County. As the conglomerate is massive and well indurated (Figure 29), costs of the rock crushing are high. There is an extensive development of this type of rock in eastern Madison County.

WATER RESOURCES

The presence or lack of a sufficient quantity of good-quality water determines, to a large measure, the population and economic trend of a region. Water is a renewable or replenishable natural resource, and an understanding of the occurrence of both surface and ground water is desirable so that a well planned search can be undertaken for sources of water supply and so that proper usage can be employed.

SURFACE WATER

The Rapidan River is the major stream of the Greene-Madison area. Tributaries of the Rapidan are the Hughes, Robertson (shown on some maps as Robinson), Conway, and South rivers. Stanardsville, county seat of Greene County, is on the drainage divide between the Rapidan and the North Fork of the Rivanna rivers. Several streams that drain the western part of Greene County are Swift Run, Roach River, and Lynch River. In the headwater areas streams that flow over the Catoctin formation are characterized by waterfalls and narrow restricted valleys. For short distances the streams flow beneath colluvial and alluvial fill in buried channels. Small, narrow flood plains are present along the lower courses of the streams, usually first as gravel accumulations that grade downstream into sandy and silty valley fills. In southeastern Madison County a fairly extensive flood plain is present along the Rapidan River. Average stream gradients are listed in Table 6.

Table 6.—Stream gradients.

	Stream distance measured	Bedrock	Average gradient in feet per mile
Rapidan River....	Headwaters to Graves Mill	Granodiorite, greenstone, & schist	244
Rapidan River....	Graves Mill to Liberty Mill	Granite gneiss	18
Rapidan River....	Liberty Mill to Robertson River	Triassic sedimentary rocks	6.5
Robertson River..	Headwaters to Banco	Greenstone & gneiss	220
Robertson River..	Banco to Rapidan River	Granite and Triassic sedimentary rocks	10
Rose River.....	Headwaters to Syria	Greenstone and granodiorite	340
Conway River....	Headwaters to Rapidan River	Greenstone, granite, and gneiss	167
South River.....	Headwaters to Rapidan River	Greenstone, gneiss, and schist	163
Roach River.....	Headwaters to Lynch River	Greenstone, granodiorite, and gneiss	150

From selected data of stream discharge (U. S. Geol. Survey Water-Supply Paper 1622), it is apparent there is a great variation in surface runoff. For example, the maximum discharge of the Rapidan River near the point where it leaves Madison County was 58,101 cubic feet per second (recorded in October 1942) and the minimum discharge at the same locality (October 1954) was 2.1 cubic feet per second. Flooding of stream lowlands has been recorded on several occasions. In August 1961 heavy rains along the east slope of the Blue Ridge caused the Conway and Rapidan Rivers to overflow some of their adjacent flood plains to a depth of 3 feet. In contrast, during times of drought, sufficient quantities of water are not available for irrigation.

Along the crest of the Blue Ridge in Greene and Madison counties, the only consumer of water is the Shenandoah National Park. Drinking water is obtained from springs at several overlooks and at some picnic and camp grounds. Water for the larger tourist facilities at Big Meadows and Lewis Mountain Lodge is also obtained from springs, but at times the flows are barely sufficient to meet minimum daily requirements. On the east slope of the Blue Ridge, springs are common. Many of these springs emerge directly from areas of granitoid rock along the lower slopes of the ridges. Stanardsville, Greene County, receives much of its water from large springs near Lydia, and the water moves by gravity flow to a reservoir just west of this town. The estimated flow is approximately 500 gallons per minute. In the central part of Greene and Madison counties, the flows of springs seldom exceeded 1 gallon per minute during the summer months of 1961.

In general, the quality of water in the streams is good, as indicated from analyses that have been made at stream gaging stations on the Rapidan and Robertson rivers (Table 7).

GROUND WATER

It has been estimated that 15 percent of total precipitation in the Piedmont province of Virginia results in ground water infiltration. For the combined area of Greene and Madison counties the amount of ground water infiltration is approximately 56 billion gallons per year, using an average annual rainfall of 45 inches. Penetration of water from rain, snow, sleet, and hail into the ground is, in general, enhanced by a slow rate of precipitation, a gently sloping to flat ground surface, a large amount of vegetation, a high atmospheric humidity, and especially, a high porosity in the soil and rock. Water percolates downward by gravity through the pore spaces between mineral and rock grains and through secondary openings such as joints, cleavage, faults, and

Table 7.—Chemical analyses of surface waters[1].

Date	Rapidan River at bridge on U. S. Highway 29 (in ppm)			Robertson River near Locust Dale (in ppm)		
	8/7/58	5/13/59	11/18/59	9/8/58	4/27/59	1/4/60
Silica	15.	6.8	8.6	9.3	7.0	9.2
Iron	0.08	0.21	0.09	0.00	0.09	0.17
Calcium	4.5	4.2	2.1	4.0	2.6	2.1
Magnesium	0.7	0.0	0.6	1.5	1.3	4.3
Sodium	3.3	3.9	1.8	3.0	8.1	2.5
Potassium	1.1	2.7	0.8	1.4	2.6	2.9
Bicarbonate	373.	17.	12.	17.	23.	10.
Sulfate	19.	5.8	4.6	5.6	6.7	13.
Chloride	18.	3.2	2.5	4.3	2.7	3.8
Fluoride	1.6	0.0	0.1	0.0	0.0	0.0
Nitrate	0.5	3.0	0.5	0.0	0.8	2.0
Total hardness	14.	8.	8.	16.	12.	23.
pH	8.3	6.6	6.9	6.6	6.9	6.2
Discharge in cubic feet per second	67.	135.	59.	66.	143.	308.

1. Virginia Div. of Water Resources, 1960, Chemical character of surface waters of Virginia: Bull. 23, pp. 36-37. Dissolved solids are expressed in parts per million, or ppm. One part per million is a unit weight of a constituent in a million unit weights of water. It should be noted that water that contains less than 60 ppm of hardness is considered relatively soft. Water with a pH above 7.0 is alkaline and below 7.0, acidic. The pH of most natural surface water varies between 6.0 and 8.0.

fractures. Water enters the vadose zone, or zone of aeration, that is beneath the ground surface. Under this zone, where the rock openings become completely saturated with water, is located the phreatic zone, or zone of saturation. Locally, however, the openings may be saturated in the zone of aeration. The surface marking the top of the saturated zone is referred to as the water table. The water table roughly parallels the topographic surface, but is at a shallower depth beneath the ground surface in a valley than under a hill. In most terrains ground water moves downslope and may intersect the ground surface at a lower elevation in the form of a spring or at the level of a stream. The fluctuation, or rise and fall, of the water table is related to the quantity of precipitation; usually the water table rises after heavy rains and falls during and after times of drought. Below the water table the movement of water depends on the topography of the area and on the quantity, spacing, continuity, and size of the rock openings. Generally, the flow of water in the saturated zone is much slower than in the zone of aeration.

Porosity, the percentage of open space in a rock, and permeability, the capacity of the rock to transmit a fluid (in this case, water), are terms used to indicate the relative water-bearing potential of a rock. For example, if 1 cubic foot of sand will hold 0.25 cubic foot of water when saturated, the porosity of the sand is said to be 25 percent. Furthermore, in some rocks with relatively high permeability water may move several feet in an hour; if the water moves at the rate of several feet per year, the permeability is relatively low.

In Greene and Madison counties weathered and stratified rocks are usually a more favorable environment for the entry, retention, and movement of water than massive igneous and metamorphic rocks. Well-sorted, coarse gravels and sands have high porosity and permeability. Granites, gneisses, and basalts have low porosity and permeability unless characterized by numerous joints, fractures or other secondary openings. Schists and phyllites usually have low permeability unless they are highly weathered or fractured.

Most wells in the area of this report are shallow and are used for farm and domestic purposes. Sufficient water is obtained from shallow wells, except in times of extreme drought.

East Slope of the Blue Ridge

Wells drilled in granitoid rock of the foothill area along the east slope of the Blue Ridge range greatly in depth and yield. It is reported that wells less than 100 feet deep normally yield 1 to 10 gallons per minute; between 100 and 200 feet the wells yield 1 to 20 gallons per minute.

Central Part of the Counties

Within the central part of Greene and Madison counties the underlying rock is granitoid, gneissic, schistose and phyllitic. There is a wide range in the water-bearing capacities of these rocks. The contact zones between granitoid masses and schistose and phyllitic rocks seem to be the most favorable location for the accumulation of water. It was noted that these associations are most conducive for the occurrence of springs.

At Stanardsville there is a deep well that is utilized to supplement the local water supply. It is reported that the well yields approximately 20 gallons per minute. There are two other wells in the town of Stanardsville, one of which is reported to be 160 feet deep and yields about 20 gallons per minute. A water well, located about 2 miles southwest of Stanardsville, is reported to have a depth of 425 feet and a

yield of about 35 gallons per minute. A water well located near the intersection of U. S. Highways 29 and 33 is reported to have a depth of 208 feet. Water was encountered at a depth of 200 feet and at the time of completion the well yielded about 20 gallons per minute.

The town of Madison utilizes water from three drilled wells that are in the Robertson River formation. These wells are 135, 298, and 735 feet deep and each yields less than 12 gallons per minute. At the time of completion in 1936 the 298-foot well had an initial yield of 70 gallons per minute. The town is located on a low ridge of granitic rock which is a drainage divide. The location of the town wells on this divide is probably responsible for the low yields.

Wells located in the Lynchburg formation east of U. S. Highway 29 generally yield small quantities of water. In the vicinity of Brightwood and Leon, wells drilled in the contact zones of granitoid and metamorphic rocks seem to develop better yields at shallower depths than wells drilled in the gneisses and schists of the Lynchburg. However, the yields are low even in these areas, seldom exceeding 5 gallons per minute. One such well drilled in 1950 near Leon yielded 2 to 3 gallons per minute from gneiss and schist at a depth of 83 feet. The static water level is about 50 feet below the ground surface. A well drilled in metamorphosed graywacke near the junction of State Roads 630 and 631 in Madison County is 370 feet deep and yields 0.5 gallon per minute. Many of the wells located close to the major streams have greater yields. A well drilled to a depth of 80 feet in Madison County near State Road 621 approximately 1 mile south of the N. B. Early Bridge and about 800 yards from the Rapidan River, yields about 40 gallons per minute from metamorphosed graywacke near a granite contact. Shallow wells in the Lynchburg formation usually yield 1 to 2 gallons per minute at depths less than 60 feet.

The quality of water from wells in the central part of the two-county area is generally good. Reports indicate that the water, low in dissolved solids, is generally soft to moderately hard. This water contains some iron; the slightly low pH tends to aid in the corrosion of pipes.

Triassic Area of Eastern Madison County

From several wells examined in the area of eastern Madison County that contain Triassic rocks, static water levels are within about 50 feet of the ground surface. Roberts (1928) reports that the ground-water level is shallow beneath areas of Triassic rocks. However some drilled wells maintain a static level more than 100 feet below the ground surface. The Woodberry Forest School has three wells on the school

property, that is located in Madison County about 1 mile east of U. S. Highway 15 at its junction with State Road 622. The main supply well is about 140 feet deep and yielded 600 gallons per minute during a 24-hour test. It yields about 35 gallons per minute and the static level is about 100 feet below the ground surface. Another well, about 130 feet deep, yields 12 gallons per minute. A third well, located about 500 feet from the main supply well, which is about 140 feet deep is practically dry.

The greenstone and diabase masses are generally nonvesicular, the conglomerates are well cemented and indurated, the sandstones are generally tightly cemented and the grains poorly sorted, and the shales are massive. However, contacts between units, especially between the sedimentary and igneous units, seem to have favorable water-bearing potential, as do northeastward- and northwestward-trending faults that are present along the westernmost outcrop of Triassic rock. Such zones may be the most productive source of ground water.

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COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES
James L. Calver
Commissioner of Mineral Resources and State Geologist

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Geologic Map
GREENE AND MADISON COUNTIES VIRGINIA

Geology by Rhesa M. Allen

SCALE 1:62500

1963

EXPLANATION

QUATERNARY

Qal — Alluvium

TRIASSIC

Tr — Newark group
Conglomerates, arkoses, sandstones, shales, Tn. *Diabase and greenstone bodies,* Tig.

CAMBRIAN

Cw — Weverton formation
Conglomerates, arkosic sandstone and siltstone.

Cl — Loudoun formation
Red spotted slates, phyllites and sericite schist.

CAMBRIAN OR PRECAMBRIAN

CpCc — Catoctin formation
Green, altered flows, amygdaloidal in part. Chlorite-amphibole schists and pyroclastics. Feeder dikes are indicated by dark green.

CpCs — Swift Run formation
Conglomerate, quartzite and slate.

PRECAMBRIAN

VIRGINIA BLUE RIDGE COMPLEX

pCm — Mechum River formation
Metamorphosed sandstones and arkoses. Schist and phyllites.

pCly — Lynchburg formation
Gneiss, mica schist, graphitic schist and metamorphosed graywacke

am — Amphibolite
Amphibole-plagioclase dikes and sills.

um — Ultramafics
Tremolite-chlorite schists, serpentine, peridotite and soapstone.

pCp — Pedlar formation
Granodiorite and unakite, slight gneissic structure.

pCor — Old Rag granite
Quartz, potash feldspar granite.

pCrr, pCrm — Robertson River formation
Hornblende granite and syenite pCrr. *Migmatitic and garnet-ilmenite facies,* pCrm.

pCrs — Marshall formation
Biotite quartz monzonite gneiss.

pCl, pClt — Lovingston formation
Biotite quartz monzonite augen gneiss, migmatitic in part pCl. *Titanium-rich facies,* pClt.

CONTACTS

exposed
approximate
covered

FAULTS

NORMAL AND REVERSE

U/D exposed
U/D approximate

U - *upthrown side*
D - *downthrown side*

THRUST

exposed
approximate
T overthrust side

TRANSVERSE

exposed
approximate
Arrows indicate relative movement

SHEAR ZONE

FOLDS

Anticline - trace of axial plane
Syncline - trace of axial plane

ATTITUDE OF ROCKS

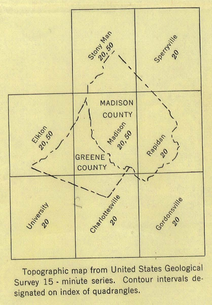
60 Strike and dip of beds
60 Strike and dip of overturned beds
Strike of vertical beds

FOLIATION

Strike and dip of foliation

MINES AND QUARRIES

2

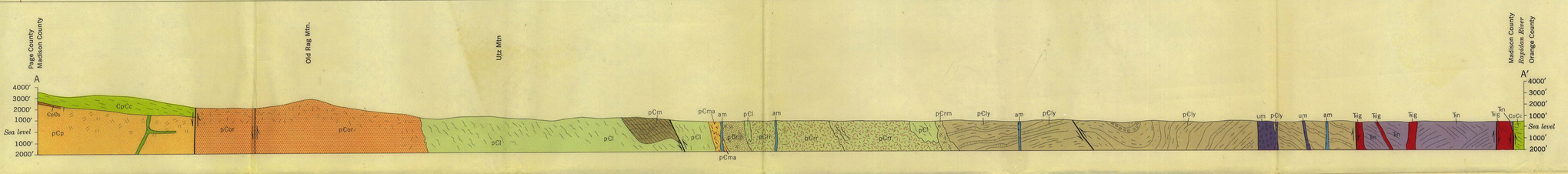


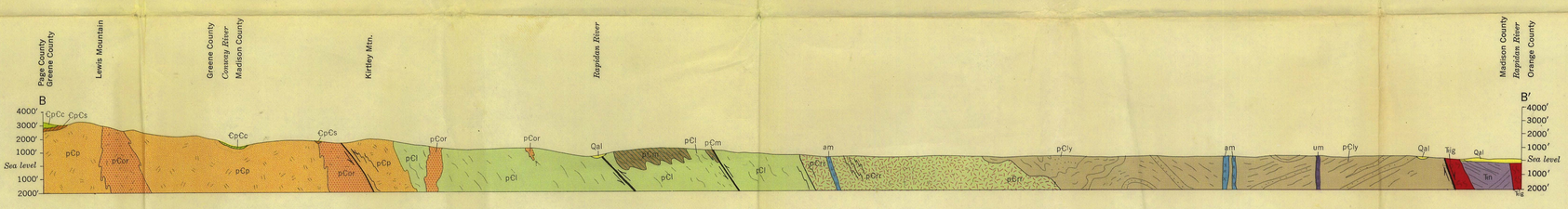
Topographic map from United States Geological Survey 15 - minute series. Contour intervals designated on index of quadrangles.

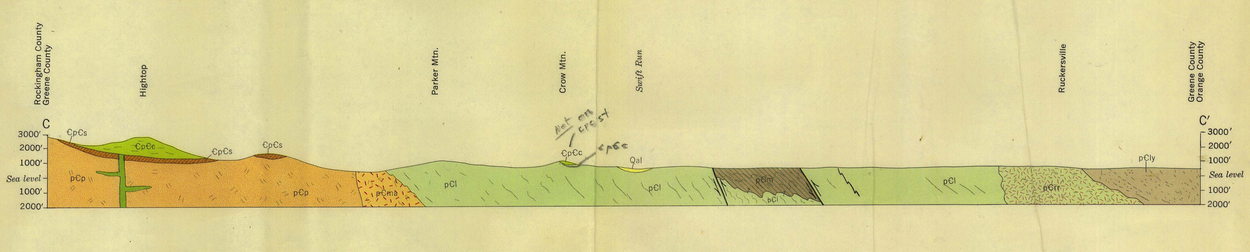
APPROXIMATE MEAN DECLINATION, 1959

Inactive Mines, Quarries and Prospects

1. Hightop (copper)
2. Tunnel Tract (Sims) (copper)
3. Dark Hollow (copper)
4. Stony Man (copper)
5. Rose River granite quarry
6. Rapidan River granite quarry
7. Granite quarry
8. Old slate quarry (?)
9. Lydia flagstone quarry
10. Roadside granite quarry
11. Granite quarry
12. Pyrite mine
13. Pyrite mine







No Vertical Exaggeration

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