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COMMONWEALTH OF VIRGINIA

DEPARTMENT OF CONSERVATION AND DEVELOPMENT

VIRGINIA DIVISION OF MINERAL RESOURCES

JAMES L. CALVER, Commissioner of Mineral Resources and State Geologist

Bulletin 74

Geology and Mineral Resources of the Lynchburg Quadrangle Virginia

By

WILLIAM RANDALL BROWN

CHARLOTTESVILLE, VIRGINIA

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COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION AND DEVELOPMENT
DIVISION OF MINERAL RESOURCES

CHARLOTTESVILLE, VIRGINIA,

April 11, 1958

To the Department of Conservation and Development:

GENTLEMEN:

I have the honor to transmit and to recommend for publication as Bulletin 74 of the Division of Mineral Resources this manuscript on the *Geology and Mineral Resources of the Lynchburg Quadrangle, Virginia,* by Dr. Wm. Randall Brown of the Department of Geology, University of Kentucky. This report contains a geologic map, a mineral resources map and illustrations depicting the geology of the Lynchburg area.

This report treats of a large variety of mineral deposits which include "Virginia greenstone," iron ore, manganese ore, barite, granitic rocks, limestone and marble. The detailed description of the geology of this area should be of great value in the development of these mineral resources.

Respectfully submitted,

JAMES L. CALVER,
Commissioner

Approved for publication:
Virginia Department of Conservation and Development
Richmond, Virginia
RAYMOND V. LONG, *Director*

CONTENTS

	Page
Abstract	1
Introduction	3
Location of the area	3
Field work and acknowledgments	3
Purpose of the study	4
Previous geologic work	4
Conclusions	5
Rocks of the area	7
General relations	7
Virginia Blue Ridge complex	7
General statement	7
Pedlar formation	9
Name and distribution	9
Lithology	9
Marshall gneiss	11
Name and distribution	11
Lithology	12
Reusens migmatite facies of Moneta gneiss	12
General statement	12
Earlier hornblende gneiss phase	13
Later leucogneiss phase	16
Basic pegmatite	16
Later dark gneiss phases	16
Origin of the Virginia Blue Ridge complex	17
Late Precambrian group	18
General statement	18
Lynchburg formation	18
General features	18
Biotite-quartz gneiss	20
Mica schist	21
Graphitic schist	21
Conglomeratic gneiss	21
Relation of Lynchburg formation to underlying rock	21
Catoctin greenstone	22
General statement	22
Lithology	25
Evington group	28
General statement	28
Sequence in the Evington group	28
Nature of faulting	30
Synclinal versus anticlinal structure in the belt of Evington rocks	30

PAGE

Minor structures 30
Conglomerates 30
Cross bedding 31
Small sedimentary features 31
Candler formation 31
Name and distribution 31
Lithology 32
Joshua formation 33
Name and occurrence 33
Lithology 33
Arch marble 33
Name and relations 33
Lithology 34
Pelier schist 34
Name and relations 34
Lithology 35
Mount Athos formation 35
Name and relations 35
Lithology 36
Slippery Creek greenstone 37
Name and relations 37
Lithology 37
Sill- and dike-like rocks 38
General statement 38
Post-Reusens hornblendic rocks 38
Occurrence and origin 38
Plagioclase amphibolite 40
Hornblende gneiss 41
Ultrabasic association of rocks 41
General statement 41
Amphibole-chlorite schist 46
Peridotite 46
Serpentinite 47
Soapstone 47
Triassic diabase 47
Age of rocks 48
Structure 50
General statement 50
Catoctin-Blue Ridge anticlinorium 50
James River synclinorium 51
Sherwill anticline 53
Martic line 53
Minor structural features 57
General statement 57
Bedding 57
Bedding foliation 57
Axial plane cleavage 57

PAGE
Fracture cleavage 57
Slip cleavage 58
Minor folds 59
Lineations other than fold axes 60
Geologic history 61
Mineral resources 64
General statement 64
Marble 64
General statement 64
Arch marble 65
Mount Athos marble 67
"Virginia Greenstone" 69
Sand 71
Granitic rocks and hornblende gneiss 71
Manganese ore 71
General features 71
Mines and prospects 73
Piedmont mine 73
Leets mine 75
Drinkard (Herbert) mine 76
Neighbours mine 76
Bell mine 76
Maddox mine 77
Mortimer mine 77
Barite 77
Iron ore 78
References cited 92
Index 97

ILLUSTRATIONS

PLATE PAGE

1. Geologic map and structure sections of the Lynchburg quadrangle, Virginia ..... in pocket

2A. Reusens migmatite in quarry at south edge of Peakland.
B. Reusens migmatite on east bank of James River below Reusens dam.. 80

3A. Part of Lynchburg anticline in Lynchburg formation on northeast side of James River opposite Lynchburg.
B. Cobbles from conglomeratic Lynchburg formation at Ivy Creek half a mile south of Peakland..... 81

4A. Quarry in Mount Athos quartzite near mouth of Slippery Creek.
B. Candler phyllite beside Highway 501 a mile southeast of Lynchburg.... 82

5A. Minor sedimentary features in sawn slab of sandy, argillaceous Arch marble in quarry near mouth of Opossum Creek.
B. Minor folds in Lynchburg formation near crest of Lynchburg anticline, Highway 130, Madison Heights.
C. Close-up of fold in 5B, showing extreme difference in thickness of bed in trough as compared to that on limb of fold..... 83

6A. Close, steep-axis folding in Arch marble at Archer Creek near "the Arch".
B. Strong "rodding" lineation in Mount Athos quartzite near Lanes Well Fork 5 miles south of Lynchburg..... 84

7A. Fracture cleavage (slip cleavage in part) in sandy, argillaceous Arch marble at quarry near mouth of Opossum Creek.
B. Slip cleavage and bedding on joint surface, J, at same locality as 7A.... 85

8A. Virginia Greenstone Company Daniel Avenue quarry, Lynchburg.
B. Same as 8A. View into quarry from the east..... 86

9A. Hand windlass over exploratory shaft at the Piedmont manganese mine 5½ miles southeast of Lynchburg.
B. View northward across workings at Bell manganese mine 5½ miles south of Lynchburg; Candler Mountain in the background..... 87

10A. Photomicrograph of porphyroblastic Candler phyllite 0.6 miles southwest of Galts Mill.
B. Photomicrograph of garnet with helicitic structure in Candler schist 2 miles southeast of Lynchburg..... 88

11A. Photomicrograph of simple monoclinal mimetic slip cleavage in Lynchburg formation on east flank of Lynchburg anticline.
B. Photomicrograph of Marshall gneiss 6½ miles northwest of Lynchburg 89

12A. Photomicrograph of hypersthene granodiorite from the Pedlar formation a mile west of Abert.
B. Photomicrograph of cobble in the conglomerate of the Lynchburg formation at Ivy Creek half a mile south of Peakland..... 90

13A. Photomicrograph of Marshall gneiss at Abert.
B. Photomicrograph of Marshall sodic granite 2½ miles northwest of Reusens 91

14. Map showing distribution of mineral resources in the Lynchburg quadrangle, Virginia .....in pocket

FIGURE PAGE

1. Index map showing location of Lynchburg quadrangle in relation to major structural features of the Piedmont-Blue Ridge region of Virginia facing page 4

2. Columnar section of rocks in the Lynchburg quadrangle, Virginia..... 8

3. Fence diagram showing relations between Catoctin greenstone (black), Lynchburg formation (stippled) and Candler formation in the west central Piedmont of Virginia. Relations in Blue Ridge adapted from Bloomer, 1950. Diagrammatic and not strictly to scale..... 19

4. Sketch of cross-cutting relationship at contact between hornblende gneiss and Lynchburg gneiss half a mile west of Madison Heights..... 39

5. Index map of structures in the Lynchburg quadrangle, Virginia..... 51

6. Sketch of slip cleavage imposed upon bedding foliation, showing theoretical development of crinkles on steep limb of asymmetric fold and simple monoclines on flatter limb..... 58

TABLES

PAGE

1. Approximate modes of typical specimens of Pedlar formation and Marshall gneiss in the Lynchburg area 10
2. Approximate modes of phases of Reusens migmatite..... 14
3. Modes of the Lynchburg formation..... 20
4. Estimated modes of greenstones..... 26
5. Relation between the stratigraphic terminology of Furcron, Espenshade, and Brown 29
6. Approximate modes of hornblendic rocks and rocks of the ultrabasic association 42
7. Chemical analyses of chlorite-amphibole schist of the ultrabasic association 44
8. Analyses of marble in vicinity of "the Arch" on the Norfolk and Western railroad 5 miles east of Lynchburg..... 66
9. Analyses of limestone and marble in the Lynchburg quadrangle..... 68

Geology and Mineral Resources of the Lynchburg Quadrangle, Virginia

By Wm. Randall Brown

ABSTRACT

The Lynchburg quadrangle is in south central Virginia near the western limit of the Piedmont physiographic province. It includes an area of about 248 square miles, mostly in Campbell County, but also partly in Amherst, Bedford, and Appomattox counties.

Rocks of the area are predominantly metasedimentary and metaigneous and, with the exception of Quaternary alluvium and very minor Triassic diabase, are probably of Precambrian and lower Paleozoic age. Three groups recognized are, from oldest to youngest: 1) a complex of granitoid, gneissic, and migmatitic rocks, called Virginia Blue Ridge complex in this report; 2) a "late Precambrian" group consisting of Lynchburg formation and Catoctin greenstone; and 3) the Evington group of metasediments and metavolcanics. These outcrop in broad northeasterly-trending belts, the positions of which are controlled by three large regional structures which extend across the quadrangle. These structures are, from northwest to southeast: part of the core and southeast flank of the Catoctin-Blue Ridge anticlinorium, the James River synclinorium, and the Sherwill anticline.

The Virginia Blue Ridge complex constitutes the core of the Catoctin-Blue Ridge anticlinorium. In this area it consists of a gradation from Pedlar formation on the northwest, through Marshall gneiss and into Reusens migmatite on the southeast. The Marshall gneiss and at least parts of the Pedlar formation appear definitely to be products of a granitization, of which the Reusens migmatite is an outer zone. These core rocks are flanked on the southeast by Lynchburg formation, which seems to rest unconformably upon the Reusens migmatite. Catoctin greenstone, which in some areas overlies the Lynchburg formation is a transgressive unit in this area, being interlayered in part with the upper Lynchburg and also with the overlying Candler formation, the oldest unit in the Evington group. This Lynchburg-Candler contact has been mapped as the Martic overthrust, but

the widely repeated general sequence: Lynchburg-Catoctin-Candler, and the transgressive nature of the Catoctin greenstone strongly oppose this interpretation.

Near the central part of the quadrangle, the Lynchburg formation and Catoctin greenstone dip southeastward beneath rocks of the Evington group, which lie in the trough of the James River synclinorium; in the southeast corner they emerge on the northwest flank of the Sherwill anticline. Within the James River synclinorium, rocks of the Evington group are closely folded and are repeated in numerous places by high-angle faults. These faults, once considered to be normal faults, are of reverse type. The nature of faulting, along with other evidences, indicate the sequence in the Evington group to be chronologically the reverse of that as previously interpreted.

Sill-like bodies of amphibolite and hornblende gneiss are abundant in parts of the Lynchburg formation. These have been generally interpreted to be metagabbros, but there are indications that many or all in this area may be products of metasomatism. Ultrabasics which occur in the Lynchburg and older rocks appear to be no younger than Catoctin greenstone; also, those in the upper Lynchburg may be volcanic rather than plutonic as commonly supposed.

Chief mineral resources in the area are marble (limestone), "Virginia Greenstone," sand, manganese, iron, barite, granite and other rough building stones. The first three are in important production at present. Manganese has been produced periodically and sporadically over the last 75 years; iron ore deposits, although not worked since the eighties, are not exhausted but are small; known deposits of barite are few and small.

INTRODUCTION

LOCATION OF THE AREA

The Lynchburg quadrangle includes portions of Campbell, Amherst, Appomattox, and Bedford counties in the western Piedmont of Virginia and has an area of about 248 square miles (Fig. 1). It is bounded by parallels 37°15′ and 37°30′ and meridians 79° and 79°15′.

FIELD WORK AND ACKNOWLEDGMENTS

The quadrangle was mapped chiefly during the summers of 1940, 1941, 1946, and 1947, at which times the writer was in the employ of the Virginia Geological Survey. He was ably assisted in the field in 1946 and 1947 by H. C. Sunderman and during a few weeks in 1950 by William B. Brent. Studies in related areas in the Piedmont were made during the years 1942-45 and 1951-54.

The writer is indebted to Dr. Arthur Bevan, former State Geologist, for suggesting the problem and for assistance of many kinds; to Mr. William M. McGill, also former State Geologist, for promoting continuance of the study; and to Dr. James L. Calver, present State Geologist, for making publication possible. Dr. J. D. Burfoot, Jr., Dr. Charles Nevin, and Dr. A. L. Anderson of Cornell University made numerous suggestions during the earlier studies. Dr. and Mrs. G. W. Stose of the U. S. Geological Survey visited the writer in the field and were most helpful throughout the investigations. Dr. G. H. Espenshade, also of the U. S. Geological Survey, and Dr. John Rodgers of Yale University, who carried out manganese studies within part of the area, were very cooperative and helpful. Valuable suggestions were also made by Dr. R. O. Bloomer of St. Lawrence University. The writer is grateful to Dr. A. A. Pegau of the Virginia Division of Mineral Resources for reading the paper and giving constructive criticism. Dr. E. O. Gooch of the Virginia Division of Mineral Resources has also supplied recent data concerning mineral operations in the area.

Finally, numerous persons in the area, particularly mineral operators, and especially L. C. Acree, Jr., S. B. Owen, L. C. Woody, and William Johnson of the Virginia Greenstone Company, Inc., have been most cooperative and have given freely of information.

PURPOSE OF THE STUDY

Within the Piedmont portion of the Southern Appalachians there are several relatively long, narrow belts of rocks of obvious sedimentary origin, generally of lower metamorphic grade and apparently younger than rocks in bordering areas, which King (1955, p. 350) has called "dejective zones." These zones appear to be more susceptible to detailed mapping and, thus, to offer more clues to the stratigraphy and structure of the Piedmont region than most areas. In addition, these dejective zones have economic significance in that they have yielded most of the marble, slate, manganese, barite, gold, pyrite, and copper produced in the Virginia Piedmont.

The Lynchburg quadrangle lies astraddle the James River synclinorium, a great dejective zone which marks the western limit of the Piedmont structural province in Virginia, at a place where outcrops are particularly good and the stratigraphic sequence is unusually complete. This quadrangle also includes part of the core and southeast flank of the Catoctin-Blue Ridge anticlinorium, the dominant structural feature of the Blue Ridge province to the west. The "Martic overthrust" has also been mapped through the quadrangle.

An effort has been made to establish, through detailed mapping on modern topographic base, relative ages and structural relations both within and between the James River synclinorium and the Catoctin-Blue Ridge anticlinorium, and to prove or disprove the existence here of the "Martic overthrust."

PREVIOUS GEOLOGIC WORK

The earliest reports relating to this area were by Britton (1881), Campbell (1882), Rogers (1884), Watson and Holden (1907), Harder (1910), and Hewitt (1916), and were concerned chiefly with limestone, iron, manganese, and "cupreous rock" of the region. A geologic map of Virginia published in 1911 and 1916 grouped most of the Lynchburg formation and injection complex of the Catoctin-Blue Ridge anticlinorium as "granite and granite gneiss," and showed the James River synclinorium as a trough of Cambrian rocks.

In 1926 Anna Jonas began broad reconnaissance studies in the Virginia Piedmont, and the results were embodied in the Geologic Map of Virginia, 1928. On this map and in later publications (Jonas, 1929, 1932) she recognized and described numerous new rock units, applying Maryland stratigraphic names to some, and introduced in this state the concept of great overthrust faults marked by zones of

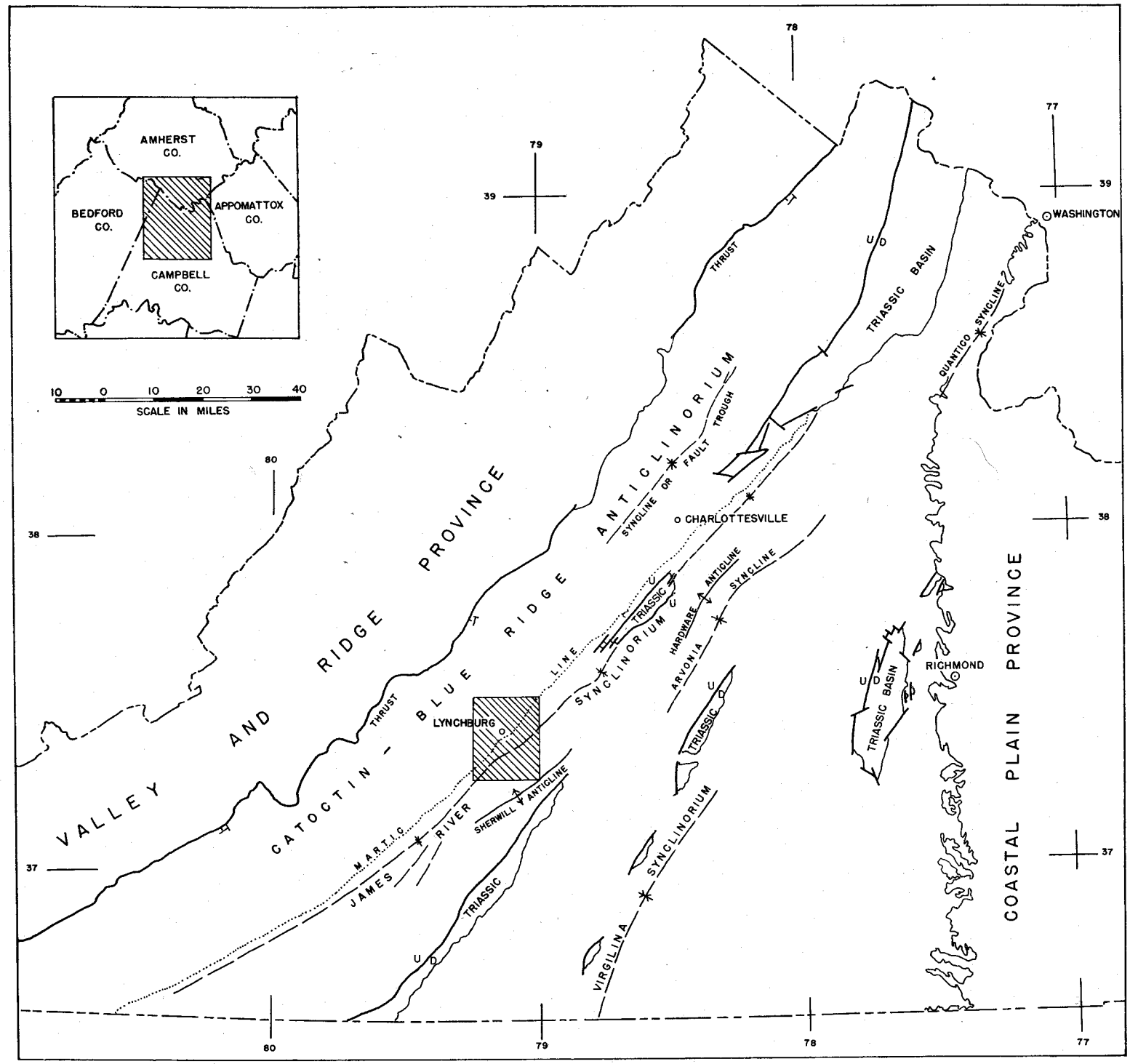


FIGURE 1.—Index map showing location of Lynchburg quadrangle in relation to major structural features of the Piedmont-Blue Ridge region of Virginia.

retrograde metamorphism. The Martic overthrust, based upon this concept, was mapped through the Lynchburg quadrangle.

Furcron, in 1935, published the results of extensive investigations in the James River Iron and Marble belt (James River synclinorium) made in the years 1925-29. His geologic map, which included part of the Lynchburg quadrangle, was the most detailed made up to that time. It was based upon poor maps and was essentially a reconnaissance. Furcron accepted the concept of the Martic overthrust but, in the area of his map, showed its trace down-faulted from view by the Catoctin Mountain border fault. The James River Iron and Marble belt, considered to be part of the Martic thrust block, was mapped as an anticlinorium broken by numerous normal faults.

In 1939, Jonas and Stose made the important interpretation that the Rockfish conglomerate, at the west border of the Lynchburg formation, first described by Nelson (1932), is evidence that the Lynchburg is younger than the "injection complex" of the Blue Ridge. They also reached the conclusion that the Lynchburg is part of a late Precambrian series topped by Catoctin metabasalt.

In 1940-41, concurrent in part with mapping near Lynchburg by the present writer, Espenshade (1952, 1954), assisted in part by John Rodgers, made a comprehensive study of manganese deposits in the James River synclinorium from the vicinity of Altavista to Howardsville. His 1954 report was accompanied by an excellent geologic map. Related studies were being made north and northwest of the Lynchburg quadrangle about this same time, by Moore (1940) and Bloomer and Bloomer (1947). Extensions of these studies later were made by Bloomer (1950) and Bloomer and Werner (1955). Contributions were also made to the knowledge of the injection complex and Lynchburg formation southwest of this quadrangle by Diggs (1955).

CONCLUSIONS

Conclusions which have been reached concerning some of the more important problems in the area are listed below.

1) The basic interpretations upon which the concept of the "Martic overthrust" in Virginia is based are untenable; and, although some fault movement has occurred locally along the Martic line, this line in Virginia is not generally a fault trace. Evidence which opposes large-scale overthrusting likewise opposes the existence of the Catoctin Mountain border fault except in vicinity of Triassic basins.

2) The sequence of formations in the Evington group of the

James River synclinorium is the chronologic reverse of that as interpreted by Furcron (1935).

3) The rocks of the James River Iron and Marble belt lie in a thrust-faulted synclinorium (James River synclinorium) rather than a normal-faulted anticlinorium.

4) The revised chronologic sequence in the James River synclinorium and the requirements of detailed mapping make desirable certain revisions in stratigraphic terminology (Fig. 2 and Table 5).

5) Lynchburg formation at its type locality is younger than the injection complex of the Blue Ridge; but older metasediments, granitized and migmatized in part, occur in the western Piedmont, Blue Ridge, and Blue Ridge Plateau regions of Virginia. In this area, portions of these older metasediments are preserved in Reusens migmatite.

6) Sill-like amphibolites ("metagabbros") in this region are largely or wholly metasomatic.

7) Peridotites, serpentinites, soapstones, and chlorite-actinolite schists ("metapyroxenite") in the upper Lynchburg formation may be of volcanic rather than plutonic origin.

ROCKS OF THE AREA

GENERAL RELATIONS

The rocks of this area, except Triassic diabase and certain pegmatites, are all metamorphic and include metasedimentary and metaigneous types. They form parts of three major structural units: 1) the Catoctin-Blue Ridge anticlinorium on the northwest, 2) the thrust-faulted James River synclinorium (James River Iron and Marble belt) extending northeastward through the central part of the quadrangle, and 3) the Sherwill anticline in the extreme southeast corner of the quadrangle (Fig. 5).

Rocks in that part of the Catoctin-Blue Ridge anticlinorium in this area consist essentially of (1) a complex of ancient schistose, gneissose, granitoid, and migmatitic rocks, referred to collectively in this paper as the Virginia Blue Ridge complex; and (2) a "Late Precambrian series" composed of Lynchburg paragneiss and Catoctin greenstone. The Lynchburg formation rests unconformably upon the Virginia Blue Ridge complex; the Catoctin greenstone is essentially at the top of the Lynchburg formation but intertongues, in part, with the upper Lynchburg formation and overlying Candler formation (Fig. 3). The Lynchburg formation and older rocks contain sill-like mafic and ultramafic bodies.

Catoctin greenstone and Lynchburg formation of the southeast flank of this anticlinorium dip southeastward beneath rocks of the Evington group lying in the James River synclinorium and are again exposed in the Sherwill anticline in the southeast part of the quadrangle. Within the James River synclinorium, rocks of the Evington group have been complexly folded and thrust-faulted.

VIRGINIA BLUE RIDGE COMPLEX

GENERAL STATEMENT

The complex of schistose, gneissose, granitoid, and migmatitic rocks, which is older than the Lynchburg and Swift Run formations, and which comprises the inner, or core, portion of the Blue Ridge structural province in Virginia has been referred to as the "injection complex" (Jonas and Stose, 1939), "granitized complex" (Bloomer, 1950), and "basement complex" (Bloomer and Werner, 1955). It is here suggested that the geographic name, Virginia Blue Ridge complex, lacking genetic and age connotations, be applied to these rocks.

The chief units which have been separated within the Virginia

Age	Group	Formation	Columnar section	Thickness (feet)	Character of Rocks
LOWER PALEOZOIC (?)	Evington Group	Slippery Creek greenstone		1000-3000	Dark green to gray, schistose to gneissose lava flows (dacite - andesite ?). Amygdaloidal in part. Tuffaceous (?) schist at base.
		Mount Athos formation		100-800	Quartzite, locally conglomeratic; mica schist; and white, gray, and pink marble. Marble in discontinuous lenses which locally grade into other facies.
		Pelier schist		400	Tan sericite-quartz schist and green-gray chloritoid-quartz-sericite schist. Some thin quartzites. Biotite porphyroblasts.
		Arch marble		400	Fine- to medium-grained, blue-gray, schistose marble and calcareous schist. Arenaceous in part.
		Joshua schist		0-1500	Blue-gray phyllite and fine-grained schist; calcareous schist and schistose marble. Biotite porphyroblasts common.
		Candler formation		1500-4000	Lustrous, gray-green phyllite and fine- to coarse-grained schists. Garnet-, staurolite-, and chloritoid-bearing facies widespread in southeastern areas. Some mica quartzites and greenstone volcanics (?). Calcareous zones and micaceous marble in upper part.
PRECAMBRIAN	"Late Precambrian" Group	Catoctin greenstone		0-1000	Dark green, fine-grained biotite-epidote-chlorite-amphibole schist and gneiss. Amygdaloidal in part.
		Lynchburg gneiss		10,000	Gray, fine- to medium-grained biotite-quartz gneiss; mica schist; and graphitic schist. hg, hornblende gneiss and amphibolite. May be metagabbro intrusives, meta-tuffs, or metasomatized portions of Lynchburg formation ub, ultrabasics; amphibole-chlorite schist, serpentine, peridotite, soapstone. Not in rocks younger than Catoctin greenstone.
	Virginia Blue Ridge Complex	Pedlar formation Marshall gneiss Reusens migmatite facies of the Moneta gneiss			p. Pedlar formation. In this area, dark greenish gray, coarse-grained granodiorite. Blue quartz is characteristic and hypersthene is common. mg, Marshall gneiss. Medium to dark gray, coarse-grained biotite-quartz monzonite gneiss. Feldspar-mica augen in parts. rm, Reusens migmatite. Migmatite of Marshall gneiss in dark dioritic hornblende gneiss; some basic pegmatites. Marshall gneiss phases are younger than the darker hornblende gneiss phases.

FIGURE 2.—Columnar section of rocks in the Lynchburg quadrangle, Virginia.

Blue Ridge complex are: Pedlar formation (formerly "hypersthene granodiorite"), Marshall gneiss, Lovingston gneiss and granite, Roseland anorthosite, and Moneta gneiss (Geologic Map of Virginia, 1928; Pegau, 1932; Bloomer and Werner, 1955). In the Lynchburg quadrangle, Pedlar formation, which occupies a small area in the extreme northwest corner, grades southeastward into Marshall gneiss which, in turn, grades into the Reusens migmatite facies of the Moneta gneiss. This border zone of Reusens migmatite about one mile wide, is bounded in most places on the southeast by a conglomeratic phase of the Lynchburg formation. In places southeast of this conglomeratic zone, Reusens migmatite, and possibly other facies of the Moneta gneiss, occur infolded with or up-faulted into Lynchburg formation.

PEDLAR FORMATION

Name and distribution.—The name Pedlar formation has been suggested by Bloomer and Werner (1955, p. 582) for the "assemblage of granitic, granodioritic, syenitic, quartz dioritic, anorthositic, and unakitic rocks undifferentiable in the field," previously mapped as chiefly hypersthene granodiorite (Geologic Map of Virginia, 1928; Jonas, 1935, Fig. 1). Typical exposures are found along the upper reaches of Pedlar River of northwestern Amherst County, Virginia. Before the name "hypersthene granodiorite" was used, Watson and Cline (1916) described the prevailing facies of this assemblage in detail and, from calculated norms, gave it the name quartz-bearing hypersthene-andesine syenite.

Pedlar formation crops out almost continuously in the northwestern part of the Catoctin-Blue Ridge anticlinorium from northern Virginia southwestward into North Carolina (Watson and Cline, 1916, Fig. 1; Jonas, 1928; 1935, Fig. 1; Bloomer and Werner, 1955, Pl. 1). Smaller bodies, inclosed in Marshall gneiss or Lovingston granite, make hills and foothill mountains in the central and southeastern parts of the anticlinorium. Pedlar formation in an area about one mile wide in the northwest corner of the Lynchburg quadrangle is part of one of these outlying bodies.

Lithology.—The prevailing facies of the Pedlar formation in the Lynchburg area is gray to gray-green, massive, medium- to coarse-grained hypersthene or hornblende-quartz monzonite. Weathered surfaces may be gray, black and white, or red-brown and usually show pitting because of selective weathering of plagioclase. Feldspar, quartz, and pyribole are evident to the unaided eye. The feldspar is gray

to gray-green and the potash variety commonly shows a somewhat waxy luster. In many places both an inconspicuous clear quartz and a more prominent gray to purplish blue quartz are present.

The microscope shows a granitoid texture, modified by replacement effects. Approximate modes from thin sections show the ratio of K feldspar to plagioclase to vary from about 1:1 to 9:7 (Table 1). Both orthoclase and microcline occur. Andesine, the most common primary plagioclase, is antiperthitic in part, largely unzoned, and generally shows very fine, sharp, tapered and bent albite and pericline twin lamellae. Hypersthene, in anhedral masses rimmed with uralite, intergrown in part with augite, is present in the less altered phases of the rock. Hornblende is common and appears to be partly primary and

TABLE 1.—*Approximate modes of typical specimens of Pedlar formation and Marshall gneiss in the Lynchburg area*

	PEDLAR FORMATION			MARSHALL GNEISS				
	1	2	3	4	5	6	7	8
Quartz	15	20	12	20	25	27	20	30
Potash feldspar and perthite	35	32	36	30	28	33	10	17
Plagioclase	35	28	28	40	34	26	60	40
Hypersthene	10	...	17	...	...	...	...	...
Augite	...	...	2	...	...	...	...	...
Hornblende	3	12	2	...	...	...	...	...
Biotite	...	6	...	6	10	10	9	10
Muscovite	...	...	...	3	1	2	...	x
Apatite	1	x	1	1	x	x	x	x
Sphene	...	x	...	x	x	1	x	x
Zircon	...	x	...	...	...	...	...	...
Epidotite and clinozoisite	...	...	...	...	2	1	1	3
Ilmenite	1	2	2	...	...	x	...	...
Magnetite	...	...	...	...	...	...	...	...
Hematite	x	...	...	...	...	...	...	...
Leucoxene	...	...	...	x	...	...	...	x
Percent anorthite in plagioclase	33	10	43	10	8	5	9	20

x Present in less than 1 percent.
1. One mile west of Abert.
2. One mile southwest of Abert, northwest corner of Lynchburg quadrangle.
3. Two and a half miles southwest of Abert.
4. Three miles southwest of Abert.
5. Three miles southwest of Abert.
6. James River bluffs at Abert.
7. Three miles northwest of Reusens.
8. U.S. Hwy. 501 two miles northwest of Reusens.

partly secondary. Nonreplacement, interstitial quartz is present in small quantity.

All thin sections show deuteric or hydrothermal effects, most common of which are silification, albitization, epidotization, sericitization, and the introduction of ilmenite, sphene, and apatite. Late quartz, which is gray to purplish blue in the hand specimen, is present in all sections as tiny "droplets" or vermicular tubes and as larger lobate masses replacing feldspars, and to a lesser extent, other minerals (Pl. 12A). Albite and oligoclase occur as veinlets in and clear rims around potash feldspars, and as intergrowths with quartz in myrmekite. Large andesine crystals, in places, have been completely replaced by a more sodic plagioclase and a swarm of secondary minerals, chiefly epidote and clinozoisite. Some potash feldspar crystals likewise show complete replacement by sodic plagioclase and abundant sericite and fine muscovite. Chessboard albite, considered to be a replacement of microcline, is also fairly common. In more altered facies of the rock, hypersthene has been partly or wholly replaced by light brown biotite and blue-green hornblende. Ilmenite, sphene, and apatite appear generally to be late and occur together as fillings between and replacements of other minerals.

MARSHALL GNEISS

Name and distribution.—Jonas (1928) mapped most of the biotite-quartz monzonitic gneisses of the Virginia Blue Ridge complex as Lovingston granite gneiss, from typical exposure at Lovingston, Nelson County, Virginia; and the name Lovingston has been retained for these gneisses by most later workers (Furcron, 1935; Moore, 1940; Brown, 1953). Recently Bloomer and Werner (1955) limited the name Lovingston to gneisses with the marked augen typical of this gneiss at the type locality and to biotite granite surrounded by this augen gneiss; to those rocks formerly called Lovingston but lacking prominent augen, they extend the name Marshall, first applied by Jonas (1928) to granitoid and gneissic rocks in vicinity of Marshall, Fauquier County, Virginia. The rocks of the Lynchburg area, previously mapped as Lovingston gneiss, are generally without these prominent augen, so, following the usage of Bloomer and Werner, they are called Marshall gneiss in this paper.

Marshall gneiss, as defined by Bloomer and Werner, comprises the major part of the exposed Virginia Blue Ridge complex in this region and is particularly widespread in the southeastern portion of this exposure. In the Lynchburg quadrangle it occupies a belt 3½ miles

wide in the northwest corner, grades into Pedlar formation on the northwest, and, with modifications, is intimately intertongued with darker gneisses to form Reusens migmatite on the southeast.

Lithology.—Bloomer and Werner (1955, p. 582) described the Marshall as "gray or green, uniformly medium-grained gneiss consisting of quartz, potash feldspar, oligoclase-andesine (An30), and biotite. Quartzo-feldspathic bands that average about an eighth of an inch thick are separated by filmlike folia of bleached and chloritized biotite." This and other facies of the rock formerly called Lovingston have been described in detail by Watson and Taber (1913, pp. 59-66) and Moore (1940).

The microscope shows that specimens from the Lynchburg area contain both microcline and orthoclase, and plagioclase from albite to middle oligoclase. Generally, potash feldspar and plagioclase are present in about equal amount but, locally, either may be in excess (Table 1). Plagioclase appears to be of two distinct types, the first of which shows no obvious replacement relations, the second being distinctly of replacement origin. The first occurs with quartz and potash feldspar in sugary-textured aggregation typical of these minerals in many gneisses. Some grains are untwinned, others show sharp albite lamellae of medium width. The second, or replacement type of plagioclase is typical of the coarser and more altered facies of the Marshall gneiss, in which it forms veinlets and protuberances in and between and clear rims about potash feldspar. Many crystals, ranging from minute to over 5 mm. in diameter, show every indication of having grown in place from centers, expanding outward, replacing on their way the rock as a whole or pushing aside constituents, like biotite, not easily replaced (Pl. 11B, 13A, 13B). Remnants of a pre-replacement fine-grained biotite gneiss are locally preserved between plagioclase metasomes. The outer rim of the metasomes is generally relatively free from inclusions and merges with indistinct boundary into the surrounding minerals. The interior of the metasomes, on the other hand, is crowded with minute grains and crystals of other secondary minerals, chiefly clinozoisite and muscovite. These minerals along with epidote, sphene, and apatite are also usually abundant outside of the metasomes, particularly along zones of gneissosity or shearing.

REUSENS MIGMATITE FACIES OF MONETA GNEISS

General statement.—The names Reusens migmatite (Brown, 1951; 1953) has been applied to those intimately and megascopically mixed

light and dark gneisses, in which the light are prevailingly younger than the dark, which occur along the southeast border of the Marshall gneiss in the Lynchburg quadrangle and adjoining areas and are typically exposed in the vicinity of Reusens on James River one mile northwest of Lynchburg. The Reusens migmatite is obviously correlative with at least part of the Moneta gneiss of Pegau (1932, pp. 22-26 and Pl. 4) and Diggs (1955); but because the latter as mapped by each of these workers appears to include rocks not obviously migmatitic, some of which are possibly Lynchburg formation, the Reusens migmatite is here considered a facies of the Moneta gneiss. In this paper the name Moneta gneiss is given the modified usage of including Reusens migmatite, Bloomer and Werner's (1955) "basement complex gneiss," and all other prevailingly non-granitoid rocks in this region which are older than Marshall-Lovingston granitization.

In its most typical development, Reusens migmatite consists of from 2 to 4 distinct interbanded and interlensed phases, ranging from almost black hornblende gneiss to white basic pegmatite (Table 2). Individual units range in thickness from a fraction of an inch to a hundred feet or more but typically measure from a few inches to a few feet. The most widespread phases are an older dark hornblende gneiss, which generally becomes increasingly prominent away from the Marshall gneiss, and a later leucogneiss which tends to prevail toward the Marshall gneiss. The leucogneiss, which is typically but not everywhere biotite-bearing, has the appearance of having been injected into and, locally, across the foliation of the dark gneiss; both gneisses are commonly cut by small basic pegmatites (Pl. 2A and 2B). At the east end of the Appalachian Power Company dam at Reusens, two hornblende schist phases are later than all others and cut across the general northeast trend of the migmatic layers.

Earlier hornblende gneiss phase.—This oldest phase is a dark gray to black, medium- to fine-grained pencil gneiss composed chiefly of variable proportions of amphibole and plagioclase (An_{23-34}) and usually some biotite, clinozoisite, sphene, apatite, ilmenite, and magnetite. Hornblende, less commonly actinolite, in rod-like crystals well oriented into a strong lineation in *a*, is the most abundant mineral. Plagioclase crystals, typically elongated with the gneissosity, tend to be glassy and untwinned, although some show clean-cut, medium to wide albite twin lamellae and imperfect progressive zoning. Diopside in porphyroblasts 1-20 mm. across, containing numerous helictitic inclusions of feldspar, actinolite, biotite, and clinozoisite

TABLE 2.—*Approximate modes of phases of Reusens migmatite*

LOCALITY	REUSENS DAM						QUARRY ½ MI. SW OF PEAKLAND			CREEK 0.7 MI. SE REUSENS			IVY CREEK 3 MI. SW PEAKLAND		
NUMBER OF SECTIONS	2	1	1	1	1		2	2		1	1	1	1	1	2
FACIES	Light gray	Medium gray	Pyroxene porphyroblastic	Dark dioritic	Green-black fracture fill and replacement	Pegmatite	Medium gray	Dark gray	Pegmatite	Light gray	Medium light gray	Medium gray	Light gray	Medium gray	Dark gray
Quartz	29	5	.....	.....	.....	.....	.....	.....	x	18	18	....	.....	5	.....
Plagioclase	52	82	40	40	.....	90	65	42	99	22	62	....	91	85	38
Potash feldspar	7	.....	.....	.....	1	.....	.....	.....	....	54	6	35	.....	.....	.....
Actinolite	.....	.....	.....	.....	.....	9	25	.....	1	....	....	....	.....	.....	.....
Hornblende	.....	12	.....	55	94	.....	.....	57	....	....	....	39	8	3	60
Diopside	.....	.....	27	.....	.....	.....	.....	.....	....	....	....	....	.....	.....	.....
Biotite	11	.....	31	4	2	1	.....	.....	....	6	10	1	.....	2	.....
Muscovite	.....	.....	.....	.....	.....	.....	.....	.....	x	x	x	....	.....	.....	.....

Chlorite	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	10	.....	.....	.....
Epidote minerals	1	x	1	x	.....	.....	10	.....	.....	.....	1	12	1	.....	1
Apatite	x	x	.....	x	x	.....	.....	.....	.....	x	x	.....	.....	.....	.....
Sphene	x	x	1	1	3	.....	x	1	.....	.....	x	3	.....	.....	1
Zircon	x	x	.....	x	.....	.....	.....	.....	.....	x	x	.....	.....	.....	.....
Carbonate	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	3	.....	.....	.....	.....
Ilmenite and magnetite	x	½	.....	x	.....	.....	.....	x	.....	.....	.....	.....	x	5	x
Hematite	x	.....	.....	.....	.....	.....	.....	x	.....	.....	.....	.....	.....	.....	.....
Garnet	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	x	.....
Pyrite	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	x	.....
Pyrrhotite	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	x	.....
Percent anorthite in plagioclase	13–17	16	19	32	.....	16	39	31–34	35	16	13	.....	14	18	32

x Present in less than 1 percent.

aligned with the earlier gneissic structure, is abundant in certain biotite-rich phases.

Later leucogneiss phase.—This phase is more variable in appearance and composition than the older hornblende gneiss phase which it seems to penetrate (Table 2). Contacts between the two are somewhat gradational or marked by a thin selvage of coarse hornblende into which minute dikelets of white minerals penetrate. The leucogneiss is medium to light gray, medium-to fine-grained, more or less gneissic, and ranges in composition from hornblende diorite to biotite granite. Thin sections show quartz and feldspar intergrown in aplitic aggregation or the two more or less segregated into lentils. Some plagioclase shows sharp albite twinning or, more rarely, imperfect progressive zoning. In places, quartz is plentiful as "droplets" in feldspar.

Although, in hand specimen, the biotitic varieties commonly closely resemble Marshall gneiss, the microscope shows these as well as most other varieties of the leucogneiss to be richer in plagioclase and poorer in potash feldspar and quartz than the Marshall gneiss. In addition, the feldspars of the leucogneiss lack the obvious replacement relations so typical of those in the Marshall, and the swarms of other secondary minerals which characterize the Marshall are also largely lacking. Typical intermineral relations in the leucogneiss, rather than showing partial in-place transformation as in the Marshall gneiss, suggest complete reorganization of substance or even, perhaps, crystallization from a fluid.

Basic pegmatite.—Pegmatites which vary in width from one inch to 10 inches and form bulges in and locally cross-cutting the earlier hornblende gneiss and later leucogneiss phases, are common in the Reusens migmatite (Pl. 2A). They are composed almost entirely of plagioclase, usually andesine, but locally contain small amounts of actinolite and biotite. Small quartz segregations and tiny flakes of muscovite were observed in a few places.

Later dark gneiss phases.—At the east end of the Appalachian Power Company dam at Reusens two dark gneiss phases cut northwestward across the prevailing northeast trend of the migmatite. One follows obvious fractures and shows marked selective replacement of the leucogneiss bands; the other has firm walls and shows little replacement of other phases. The first is dark green to black in color, is composed largely of biotite and actinolite with lesser plagioclase and clinozoisite, and contains porphyroblasts of diopside and actinolite.

The second is nearly black and is made up chiefly of fine needles of hornblende and to a lesser extent of albite and ilmenite.

ORIGIN OF THE VIRGINIA BLUE RIDGE COMPLEX

Jonas (1928) interpreted the Pedlar formation and Marshall gneiss as intrusive into Lovingston gneiss, but Bloomer (1950, p. 759) concludes that the three are intergradational and represent stages in granitization. Marshall gneiss in the Lynchburg quadrangle, from the obvious growth of feldspars in place and introduction of many other minerals, and the remnants of quartz-rich gneiss between metasomes, appears definitely to be a product of more or less in-place transformation, possibly from a biotite-quartz gneiss. Pedlar formation, completely gradational into Marshall gneiss, shows similar signs of metasomatism, and is probably the product of more advanced effects of the same processes which gave the Marshall gneiss its prevailing characteristics; whether it ever attained the ultimate in these effects, palingenesis or magmatism, is unknown. Reusens migmatite is interpreted as an outer border zone to these granite-forming processes. The substance in the leucogneiss phase of this migmatite appears, however, to have undergone near or complete reorganization, possibly crystallization from a fluid, so that remnants of older rock in this phase are absent or uncommon. The common occurrence of such remnants in the Marshall gneiss, therefore, shows that the Marshall gneiss never went through a migmatitic stage resembling the Reusens migmatite.

The leucogneiss of the Reusens migmatite is considered by this writer to be a segregate, partly of local derivation and partly, perhaps, from inner zones of migmatism and magmatism, which has undergone a certain degree of mobility with some injection into and minor cross cutting of older hornblende gneiss. The original nature of this older hornblende gneiss is uncertain. It may have been mafic metaigneous rock; but the rather definite position of these and similar mafic rocks in the general zonation about these and many other granitoid bodies would seem to indicate that their mafic composition is at least partially due to the granite-forming processes. Perhaps this older gneiss was originally similar to the meta-sedimentary biotite schists and gneisses of the Moneta gneiss southwest of this area at a distance from the granitized complex. If so, prior to the development of the leucogneiss phase, there must have been a transfer of substance, including a removal of silica and potash and an introduction of Fe, Mg, and Ca, to form something of a "basic front."

LATE PRECAMBRIAN GROUP

GENERAL STATEMENT

In this paper the usage of discussing Catoctin greenstone and underlying rocks younger than Virginia Blue Ridge complex as "late Precambrian" (Jonas and Stose, 1939; Bloomer and Werner, 1955) is followed, but it must be emphasized that the Catoctin and Lynchburg formation included under this heading are strictly rock units with only general time connotations. The Catoctin greenstone, although a relatively discrete formational unit in the Blue Ridge and northwestern Piedmont, is essentially a transgressive and intertonguing unit elsewhere in the Piedmont. Its range of stratigraphic occurrence, however, is probably rather definite (Fig. 3).

LYNCHBURG FORMATION

General features.—In this quadrangle, Lynchburg formation (Jonas, 1927, p. 845), typically exposed at the city of Lynchburg, appears to overlie unconformably the Reusens migmatite facies of the Moneta gneiss and to lie conformably beneath Candler formation or, in places, the transgressive Catoctin greenstone. Where Lynchburg and Candler lithologies are not separated by greenstone, the change from one to the other varies from abrupt to gradational over a few hundred feet.

The Geologic Map of Virginia (1928) shows Lynchburg formation exposed almost continuously from Culpeper County southwestward into North Carolina. Much rock mapped as Loudoun also now is known to be Lynchburg; and much of that mapped as Lynchburg, chiefly southwest of James River, as pointed out by Pegau (1932, pp. 22-26), Bloomer (1950, p. 765), and Diggs (1955), is very probably not Lynchburg. Reconnaissance tracing by H. C. Sunderman and the writer, however, appeared to show Lynchburg formation to be continuous southwestward from the city of Lynchburg at least as far as east-central Franklin County, Virginia. Areas of the Lynchburg formation probably also occur northwest of this main outcrop belt infolded with older rocks as interpreted by Diggs (1955).

In this quadrangle, the Lynchburg formation forms two outcrop belts, one, about 5 miles wide, extending northeastward through the west central part of the quadrangle, and the other, 2½ miles wide, crossing the southeastern corner. Chief lithologic types are: biotite-quartz gneiss, mica schist, graphitic schist, and conglomeratic gneiss.

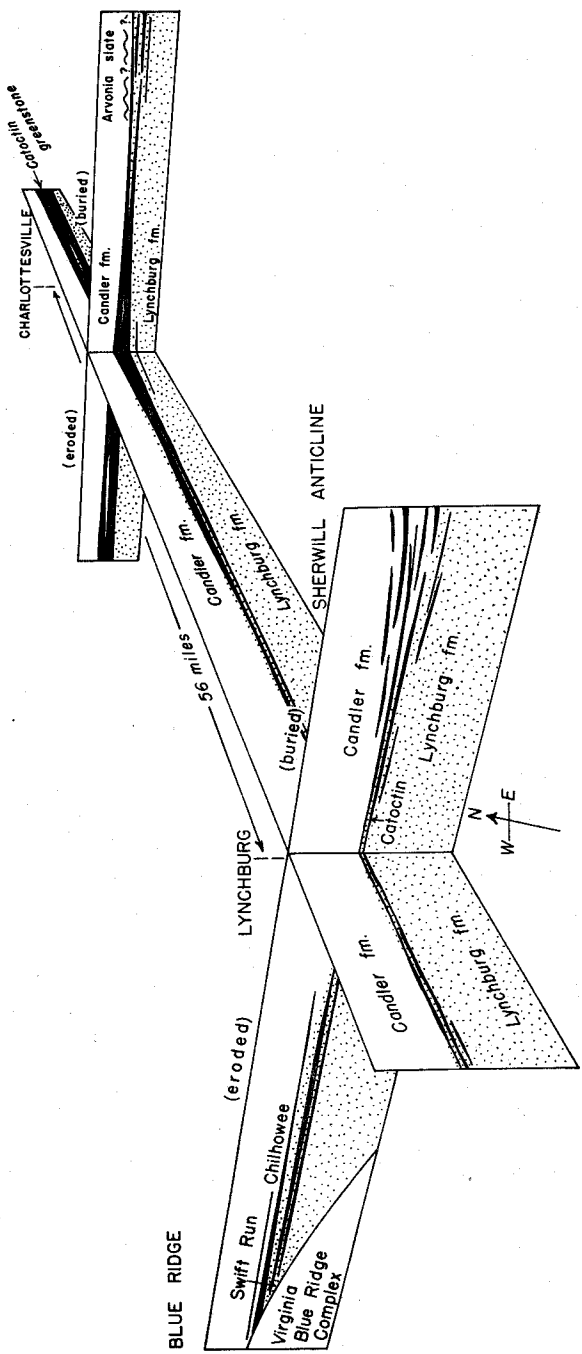


FIGURE 3.—Fence diagram showing relations between Catoctin greenstone (black), Lynchburg formation (stippled) and Candler formation in the west central Piedmont of Virginia. Relations in Blue Ridge adapted from Bloomer, 1950. Diagrammatic and not strictly to scale.

TABLE 3.—*Modes* of the Lynchburg formation*

	Catoctin-Blue Ridge Anticlinorium				Sherwill Anticline	
	1	2	3	4	5	6
Quartz	67	52	55	39	51	50
Potash feldspar	13	.....	.....	.....	14	12
Oligoclase	.....	35	28	.....	5	6
Andesine	2	.....	.....	.....	.....	.....
Biotite	17	9	17	2	22	21
Muscovite	1	1	.....	57	8	8
Garnet	.....	x	x	.....	.....	x
Sphene	x	x	.....	1	x	3
Apatite	x	1	x	1	.....	x
Epidote and clinozoisite	.....	2	.....	.....	.....	x
Zircon	x	x	x	x	.....	x
Chlorite	.....	.....	x	.....	.....	.....
Magnetite	.....	x	x	.....	.....	.....
Hematite	.....	x	.....	.....	x	.....
Pyrrhotite	.....	x	x	x	x	.....
Leucoxene	.....	.....	.....	.....	x	.....

* Percentages determined by point count in thin sections of typical specimens. Localities are:
1. Gneiss one mile north of Tomahawk Mill, and 2 miles southwest of Lynchburg.
2. Gneiss north side James River opposite Lynchburg, 100 feet west of old U.S. Hwy. 29 bridge.
3. Gneiss north side James River at U. S. Hwy. 29 bridge.
4. Schist one fourth mile southeast of No. 3.
5. Conglomeratic facies at Button Creek 3½ miles southeast of Rustburg.
6. Gneiss at Button Creek 4½ miles southeast of Rustburg.

x Present in less than 1 percent.

Sill-like bodies of amphibolite and hornblende gneiss, and less abundant ultrabasics and small pegmatites occur in the Lynchburg formation of both outcrop belts. Just west of Lynchburg, in a belt 2-3 miles wide, amphibolites and hornblende gneisses are so abundant that they cannot be accurately mapped. The intervening mica schists and gneisses are typical Lynchburg formation, and have been mapped as such, but it is quite possible that many or all of both the hornblende-rich bodies and the Lynchburg-like rocks of this belt are actually pre-Lynchburg Moneta gneiss.

Biotite-quartz gneiss.—Gneiss in layers of varying thicknesses separated by mica schist, is generally the most prominent facies of the formation. It is typically a light to dark gray "salt and pepper" rock, composed essentially of quartz, biotite, muscovite, and variable feldspar

(Table 3). Almandite porphyroblasts are common. A narrow zone of kyanite- and, locally, andalusite-bearing gneiss and schist extends from half a mile west of the Lynchburg hospital northeastward along a ridge just east of Rosenwald School. In parts of this zone, andalusite crystals up to 1½ inches long, largely altered to sericite and quartz, occur abundantly in the soil.

The microscope shows that biotite is generally more abundant, better oriented, and of earlier development than muscovite. Plagioclase, of composition oligoclase to andesine, is usually more plentiful than potash feldspar in the gneiss of the western belt; whereas the reverse is true in that from the eastern belt.

Mica schist.—Biotite-muscovite schist occurs in layers between more massive beds of gneiss and, locally, is the predominant facies. It is medium- to fine-grained, light to dark gray when fresh, and weathers yellowish brown.

Graphitic schist.—Gray to black schists, consisting chiefly of sericite, finely disseminated graphite, biotite, and more or less intermixed or segregated fine quartz, are common in the Lynchburg formation. Attempts to use these schists as key horizons for mapping intraformational structures were not successful, probably because of poor outcrops, abundant intrusives, and the complexity of the structure.

Conglomeratic gneiss.—No conglomerate comparable to the great fanglomerate-like mass at Rockfish (Nelson, 1932; Bloomer, 1950, pp. 761-763) in Nelson County occurs in the Lynchburg quadrangle; but conglomeratic beds, probably more or less correlative with the Rockfish conglomerate, occur at or near the base of the Lynchburg formation in most places along its northwest border in this quardrangle and were extremely useful in the mapping of this complex border zone.

Good exposures are in a creek three quarters of a mile southeast of Reusens and near the crossing of State Road 672 and Ivy Creek 2½ miles northwest of Lynchburg. At these places, well-rounded pebbles and cobbles, some 5 inches long, are common (Pl. 3B). The smaller ones are made up mainly of quartz and feldspar and the larger ones of gneissic biotite sodaclase granite and granodiorite. Thin sections of the rock clasts show abundant spotting with small blebs of quartz, which is a characteristic of the granitoid rocks of the Virginia Blue Ridge complex to the west (Pl. 12A and 12B).

Relation of Lynchburg formation to underlying rock.—The Marshall and Lovingston gneisses of the Virginia Blue Ridge complex from

Amherst County southwestward are bordered in most places on the southeast by rocks of an older formation, the Reusens migmatite, which resembles rocks in the Lynchburg formation. This formation contains segregations and/or injections that are similar to the nearby Marshall and Lovingston gneisses. Jonas (1928), interpreting these older rocks to be part of the Lynchburg formation, mapped them with rocks of this formation and described the Lynchburg formation as being intruded by the Lovingston and Marshall gneisses. From Amherst County northeastward, where injected rocks of this type are largely absent or not exposed, she (Jonas, 1928) and Furcron (1935, pp. 37-38 and Pl. 1) mapped as Loudoun formation those rocks which here appear clearly to lap unconformably upon the Virginia Blue Ridge complex. Later, when Jonas and Stose (1939) published their conclusion, based mainly upon the Rockfish conglomerate (Nelson, 1932), that the Lynchburg formation is younger than the Virginia Blue Ridge complex, much rock mapped as Loudoun formation was seen to be Lynchburg formation and the age relations picture in this region was greatly simplified.

In the Lynchburg area relations are less obvious than to the northeast. Pre-Lynchburg Reusens migmatite, resembling the Lynchburg formation in part, lies between the Marshall gneiss and the Lynchburg formation; but the Lynchburg formation adjacent to the Reusens migmatite, like the Lynchburg formation adjacent to the Marshall-Lovingston complex to the northeast, is generally a conglomeratic gneiss containing pebbles closely resembling facies of the Marshall-Lovingston-Pedlar complex. Additional evidence that the Lynchburg formation at its type locality is younger than this complex is that the Lynchburg formation dips almost uniformly southeastward from its anticline at the city of Lynchburg, with no suggestion of structural or stratigraphic discontinuity, to where it is interlayered with the overlying Catoctin greenstone. This interlayering of the Lynchburg formation with Catoctin greenstone, which in places in the Blue Ridge to the west seems unquestionably to rest unconformably upon the Virginia Blue Ridge complex (Jonas and Stose, 1939, pp. 579-580; Bloomer and Bloomer, 1947, pp. 95-97; King, 1949, p. 526), precludes the possibility that the lower part of this sequence of surficial rocks is older than this complex.

CATOCTIN GREENSTONE

General statement.—Catoctin greenstone, consisting essentially of basaltic and/or andesitic volcanics, was named by Keith (1894, p. 306)

from Catoctin Mountin, Maryland. It crops out from a place 10 miles south of Carlyle, Pennsylvania, southwestward through central Virginia. In Virginia, it forms a northwestern belt following the summit area of the Blue Ridge, and a southeastern "Carter Mountain" belt which passes just east of Charlottesville and includes Bull, Southwestern, Carter, and Green mountains. Greenstones of probable Catoctin age also crop out less extensively farther east in the Piedmont.

In most areas some sedimentary layers occur interlayered with Catoctin greenstone. In the main belts of outcrop in the Blue Ridge and northwestern Piedmont these are relatively few and widely spaced; farther to the southeast and southwest, however, the relationship tends to become reversed, with relatively thin greenstones interspersed through considerable thicknesses of metasediment (Fig. 3). Bloomer (1950, pp. 771-775) in dealing with the first relationship considered the sedimentary layers to be members in his "Catoctin formation." In mapping the Lynchburg quadrangle, however, where interlayered metasediment locally predominates over greenstone, it was considered more practical to limit the name Catoctin to the greenstones and map the metasediments as Lynchburg and Candler formations according to lithology.

In the western Piedmont of Virginia the Catoctin occupies a general stratigraphic position at or near the change from Lynchburg to Candler lithology; and from the vicinity of Albemarle County northward, where it is thick and includes few sedimentary units, it is convenient to consider that the "Catoctin formation" overlies Lynchburg formation and underlies the Candler formation. Elsewhere in the western Piedmont, however, it must be recognized that the greenstones intertongue, in places, with both Lynchburg and Candler lithologies and do not everywhere occur precisely at the place of this lithologic change (Fig. 3 and Pl. 1).

Catoctin greenstone of the Carter Mountain belt extends, with minor breaks, diagonally across the Lynchburg quadrangle, cropping out along the west flank of the James River syclinorium. From here it dips southeastward beneath rocks of this synclinorium and emerges on the east flank, about the Sherwill anticline in the southeastern part of the quadrangle. On the west flank of the synclinorium greenstones are interlayered in part with rocks of Lynchburg lithology; on the east flank they occur between rocks of Lynchburg and Candler lithologies as well as in numerous places within the broad belt of the Candler formation on this flank of the synclinorium. These relationships show: 1) Candler-type sedimentation was taking place to the

southeast while sediments of Lynchburg type were still being deposited to the northwest, 2) Catoctin volcanism continued longer in the southeast than in the northwest, or 3) both conditions were effective.

The composition of the Catoctin greenstone, its fine-grained texture, amygdules, and concordant relations with enclosing metasediments seem to show that in this area, as in the Blue Ridge, it is of volcanic origin. The thickly interlayered Candler sediments on the southeast flank of the synclinorium strongly suggest submarine volcanism during Candler sedimentation. Catoctin greenstone on the northwest flank of the synclinorium with its relatively small amount of interlayered metasediment may have been poured out near shore or on land. This writer concurs with Bloomer (1950, p. 773) in the opinion that the Catoctin greenstone is analogous to the spilitic lavas which characterize eugeosynclinal environments about the world. Reed (1955, pp. 494-496), on the other hand, contends that the Catoctin greenstone is not spilitic but is plateau basalt of tholeiitic type. Reed's studies, however, were in the northwestern part of the Blue Ridge near the western limit of the Catoctin onlap, where accumulation of geosynclinal sediments had not, or had but barely begun by Catoctin time. In the Piedmont not many miles southeast of the Blue Ridge, however, 6000 to 10,000 feet of geosynclinal sediment had accumulated by this time. Admittedly, pillow lavas have not been observed in the Lynchburg area, but the associated great thicknesses of graywacke sediments with occasional limestone members, mentioned by Reed as lacking, are present.

On the southeast side of the James River synclinorium, quartzites are almost invariably associated with the greenstones. Furcron (1935, p. 57) suggests that ". . . each outpouring of lava may have been accompanied by a slight relative elevation of adjacent lands so that erosion and clastic sedimentation were renewed." Another possible explanation is that the lavas formed local highs in the basin of sedimentation upon which waves and currents winnowed out the finer sediment leaving chiefly sand. It is also possible that some of these quartzites are metamorphosed radiolarian cherts, so typically associated with spilitic lavas elsewhere.

As with most spilitic lavas described in other orogenic belts, Catoctin greenstone of the western Piedmont of Virginia is often closely associated with altered ultrabasics like soapstone, serpentine, and peridotite. Concerning this association, Barth (1952, p. 185) concludes, ". . . it is possible that the primary olivine-basalt magma of the depths

of the geosynclines was activated by the initial orogenic movements, squeezed and intruded into the sedimentary strata, filtered and strained with consequent separation of olivine and other early precipitants, which subsequently were made over into peridotites and serpentines. The strained-off magma in the usual way, through fractional crystallization under assimilatory control, gave birth to one or the other of the various rock series belonging to the heterogeneous ophiolite [spilite] family." For relations between ultrabasics and Catoctin greenstone in this area, see the discussion of ultrabasics.

Lithology.—Catoctin greenstone of Maryland and northern Virginia has been described in detail by Keith (1894, pp. 306-309) and Whitaker (1955, pp. 438-441), and that of the central and northern Blue Ridge of Virginia by Bloomer and Bloomer (1947) and Reed (1955). Catoctin greenstone in the Lynchburg area, except for a higher degree of metamorphism, is generally similar to that in these regions. It is usually dark green to gray-green, fine-grained, and more or less schistose; coarser, more feldspathic facies are finely gneissic. Amphibole, feldspar, epidote, chlorite, biotite, and quartz may sometimes be indentified with a hand lens. A yellow-green facies rich in epidote and quartz (epidosite), a product of replacement or possibly originally a tuffaceous sandstone, occurs in many places. In weathered form, the Catoctin greenstone is easily recognized by its light reddish-brown color, light weight, "punky" feel under the hammer, and usual platy form.

The microscope shows Catoctin greenstone of the Lynchburg area generally to be richer in amphibole and poorer in feldspar than is Catoctin greenstone of the same outcrop belt farther to the northeast or of the Blue Ridge belt (Table 4). This difference is probably more an expression of higher grade metamorphism in this area than it is of an original difference in composition. As Harker (1939, pp. 282-283) has pointed out, it appears that feldspar substance may be absorbed into a complex amphibole molecule under higher grade metamorphism. Existing plagioclase, of composition An_{2-20}, was originally more calcic, much anorthite component having gone into epidote and/or clinozoisite which everywhere typify the Catoctin.

All minerals appear to be the product of recrystallization or neomineralization, and original igneous textures have been largely or completely obliterated in the metamorphism. Plagioclase, with quartz if present, usually forms a background matrix upon which are imposed ragged crystals of amphibole, usually actinolite; abundant grains of epidote and clinozoisite; and more or less aligned anhedral

TABLE 4.—*Estimated modes of greenstones*

	Catoctin Greenstone												Slippery Creek Greenstone		
	Lynchburg Quadrangle								North and Northeast of Lynchburg Quadrangle				Lynchburg Quadrangle		
	West flank James River synclinorium						East flank synclinorium								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Quartz	10	.....	1	15	30	.....	.....	30	2	10	5	.....	.....	3	.....
Plagioclase	38	20	.....	20	.....	30	35	.....	50	30	25	45	55	50	65
Hornblende	.....	.....	.....	.....	.....	.....	.....	15	.....	.....	.....	.....	.....	.....	.....
Actinolite	40	65	40	60	.....	30	27	.....	13	20	.....	.....	37	12	8
Biotite	.....	2	.....	2	.....	.....	.....	.....	14	.....	.....	.....	.....	20	6
Epidote and clinozoisite	12	12	55	1	15	15	38	54	20	5	30	30	3	2	10
Chlorite	.....	.....	1	.....	50	20	.....	.....	.....	20	40	20	.....	8	6
Carbonate	.....	.....	3	.....	5	3	.....	.....	.....	.....	.....	.....	.....	.....	x
Sphene	.....	½	.....	1	.....	2	.....	.....	x	.....	.....	.....	2	x	3
Magnetite and ilmenite	.....	½	.....	1	.....	.....	.....	1	1	3	.....	4	3	5	2
Apatite	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	x	.....
Clay minerals	.....	.....	.....	.....	.....	.....	.....	.....	.....	12	.....	.....	.....	.....	.....
Leucoxene	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1	.....	.....	.....

Percent anorthite in plagioclase	16	3	.....	6	.....	2	20	.....	4	18	18	6	2	3	4
Approximate average grain size (mm.) feldspar and quartz	0.06	0.04	.....	0.07	.....	0.05	0.12	0.10	0.05	0.03	0.15	0.06	0.06	0.04	0.12
Amphibole	0.07	0.06	0.14	0.2	.....	2.0	0.14	0.08	0.08	0.06	.....	.....	0.18	0.07	0.07

x Present in less than 1 percent.
1. One and a fourth miles southwest of Brightwell Mill, 5 miles northeast of Lynchburg.
2. Brightwell Mill.
3. U.S. Hwy. 29, 2 miles southwest of Lynchburg.
4. James River 1½ miles southeast of Madison Heights.
5. Two and a half miles north of Six Mile Station.
6. Two and a half miles north of Six Mile Station.
7. Four miles east of Rustburg.
8. One and three-fourths miles south of Rustburg.
9. Rockfish River, two miles southeast of Schuyler, Albemarle County.
10. Carters Bridge, 8 miles southwest of Charlottesville, Albemarle County.
11. Rapidan River, 11 miles northeast of Orange, Orange County.
12. U.S. Hwy. 250 at Rockfish Gap, crest of Blue Ridge, Albemarle County.
13. Two miles south-southeast of Lawyer.
14. Oxford Furnace.
15. One mile northwest of Stapleton.

flakes of biotite and chlorite. Sphene, magnetite, and ilmenite are common accessories. Amygdules over 1-2 mm. in diameter are only locally present, but smaller amygdules can be found in most thin sections. These are usually oval to lenticular and are filled with varying proportions of epidote, albite, quartz, chlorite, and actinolite.

EVINGTON GROUP

GENERAL STATEMENT

The Evington group (Brown, 1951; 1953, pp. 91-93; Espenshade, 1954, pp. 14-20) comprises the stratigraphic sequence: Candler formation through Slippery Creek Greenstone volcanics, which occupies the medial portion of the James River synclinorium in this region and which is typically exposed in vicinity of Evington 4 miles southwest of the Lynchburg quadrangle. In this paper, those greenstones which intertongue with the Candler formation are considered to belong to the Catoctin period of volcanism and are not part of the Evington group.

Jonas (1928), on the basis of lithology, correlated rocks of this group with the Glenarm series of Maryland and applied the name Wissahickon, in part, to rocks here called Candler, and Cockeysville to the marbles in the group. Furcron (1935) acepted these correlations. In the Glenarm of Maryland, Cockeysville marble underlies the Wissahickon formation; but in this area evidence indicates that the sequence is the chronologic reverse of that as interpreted by Furcron and the marbles are younger than the rocks called Wissahickon. It is possible and even probable that rocks of the Glenarm series are at least partly equivalent to those of the Evington group; but, in view of the miles separating the two and this difference in chronologic sequence, renaming has been considered desirable (Table 5).

SEQUENCE IN THE EVINGTON GROUP

Evidence to show that the sequence in the Evington group is the chronologic reverse of that proposed by Furcron (1935) was first presented by Brown (1941). Espenshade (1954, pp. 15, 23, 27, 32-33) states a preference for this reverse sequence, citing drag folds as chief, but not completely conclusive, evidence. Since the early observations outlined in 1941, the present writer has made an intensive study of structural and sedimentary features in an effort to prove beyond question which sequence obtains. No evidence for the chronology of

TABLE 5.—*Relation between the stratigraphic terminology of Furcron, Espenshade, and Brown*

USAGE IN THIS PAPER (BROWN, 1951, 1953)		FURCRON (1935)		ESPENSHADE (1954)
EVINGTON GROUP	Slippery Creek greenstone volcanics (youngest fm.)	GLENARM SERIES	Mount Athos greenstone or "Lower greenstone flows" (oldest fm.)	EVINGTON GROUP	Younger greenstone (youngest fm.)
	Mount Athos formation		Mount Athos formation		Mount Athos formation
	Pelier schist				
	Arch marble		Cockeysville marble		Archer Creek formation
	Joshua schist				
	Candler formation (oldest fm.)		Wissahickon formation (youngest fm.)		Candler formation (oldest fm.)

Furcron has been found; and perhaps none of the evidences for the reverse sequence summarized below is absolutely conclusive, but it is felt that the weight of total evidence is very great.

1. *Nature of faulting.*—Furcron, because his "younger" formations border most faults on the southeast, mapped all faults as normal with downdropped blocks on the southeast. Detailed mapping on large-scale base maps, however, has shown the faults to have the sinuous trace, characteristic overriding relationships, and outlying klippe which typify thrust faults (Pl. 1). The formations which Furcron considered "younger," therefore, definitely appear to be older units in the sequence which have been thrust northwestward over younger units.

2. *Synclinal versus anticlinal structure in the belt of Evington rocks.*—In the outcrop belt occupied by rocks of the Evington group, the medial position of Furcron's "older" formations and the outer position of his "younger" formations would seem to indicate the general structure to be anticlinal. On the northwest side of this belt, however, bedding dips southeastward and that on the southeast side stands vertical or dips north to northwest indicating a synclinal structure. In addition, Lynchburg formation, which in this area outcrops on both sides of the belt of Evington rocks, is shown to be older than these rocks by: 1) it dips toward them on both sides, and 2) it contains abundant mafic and ultramafic bodies not found in rocks of the Evington group. The presence of older rocks on both flanks of a syncline is expectable; but their presence on the flanks of an anticline, as required by Furcron's sequence, could be explained only in terms of faulting. Evidences opposing such a fault relationship (the "Martic overthrust") are outlined in the discussion of structure.

3. *Minor structures.*—Drag folds, and slip and axial plane cleavage in conjunction with bedding in Arch marble indicate that the Arch marble is older than Pelier schist (Pl. 7A and 7B). To check the possibility that cleavage-bedding relations had been rendered unreliable by extreme deformation or more than one deformation, these relations were checked in definite visible folds along James River. Not only were folds observed in Arch marble, but also in Lynchburg formation which, being older than rocks of the Evington group, must have gone through all deformations involving this group. In every instance, cleavages approached parallelism with the fold axial planes.

4. *Conglomerates.*—Mount Athos quartzite commonly becomes coarser toward Pelier schist and locally overlies it with heavy basal

conglomerate. Such a conglomerate is beautifully developed in the river bluff immediately south of Six Mile Station.

5. *Cross bedding.*—Good cross bedding is rarely seen in rocks of the Evington group, but where observed, as near Mount Athos in a sandy facies of the Arch marble dipping beneath Pelier schist, it appeared distinctly to show the beds to be upright.

6. *Small sedimentary features.*—Polished surfaces on thin and thick sections from numerous specimens of thinly bedded Arch marble from near Mount Athos were studied for sedimentary features which might indicate tops of beds. Although inequivocal evidence was largely lacking, rather good cross bedding and small sand ripple ridges with overlapping layers of finer sediment were found (Pl. 5A). These, along with the accompanying cleavage, show the marble, which at this place dips beneath Pelier schist, to be upright.

CANDLER FORMATION

Name and distribution.—The Candler formation, named from Candler Mountain 2½ miles south of Lynchburg (Brown, 1951, 1953, Fig. 1; Espenshade, 1954, pp. 14-16), is the oldest and most widespread formation in the Evington group. Essentially, it includes the phyllites, schists, thin quartzites and gray marbles that lie above Lynchburg formation and below Joshua schist. Catoctin greenstones commonly occur between and/or intertongued with the Candler formation and Lynchburg formation, but where there is no intervening greenstone the change from Candler to Lynchburg lithology varies from abrupt to gradational through a thickness of several hundred feet. The Candler-Joshua contact is everywhere gradational.

The Candler formation is continuously exposed from Patrick County at the North Carolina line northeastward into northern Orange County where it passes beneath Triassic beds. Its eastern extent has been only partially determined (Brown and Sunderman, 1954). From Albemarle County northeastward, the Candler includes the Esmont slates and other rocks designated as Loudoun formation on the Geologic Map of Virginia (1928). In view of the confused usage of the name Loudoun in this region (Bloomer, 1950, p. 766), use of this name in the Piedmont of Virginia probably should be abandoned.

In the Lynchburg quadrangle, the Candler formation is exposed in two northeasterly-trending belts, one from a half to 2 miles wide on the northwest limb and the other about 5 miles wide on the southeast

limb of the James River synclinorium. Faulting and tight folding have affected the width of outcrop and make accurate determinations of thickness impossible. Estimated thicknesses range from about 1500 to 5000 feet.

Lithology.—The Candler formation consists chiefly of phyllite except in the south central part of the quadrangle where garnet-mica and staurolite-garnet-mica schists predominate. Thin micaceous quartzites are common and are nearly constant associates of greenstones in the eastern belt of the Candler formation. Chloritoid schists, calcareous zones, and lenses of impure gray marble occur locally.

Phyllite of the Candler formation is a highly fissile, lustrous, gray to greenish gray rock, weathering to light tan, and composed chiefly of quartz, chlorite, and sericite. Discrete mica flakes generally cannot be discerned with the naked eye. Quartz usually shows more or less segregation into thin bands between the platy minerals, or into lenses from less than a millimeter to over a foot thick. Ankerite is present in some of the lenses. Foliation surfaces in most of the phyllite are curved, causing the rock to break into lentils (Pl. 4B); but parallel slaty cleavage prevails locally. Jonas (1932, pp. 35-37) has called this phyllite, "phyllonite," implying that its phyllitic character is the result of mylonitization of a coarser-grained rock. Movement along multiple slip planes and some crushing and smearing out of grains have undoubtedly occurred, but evidence that the rock was generally much coarser than at present appears to be lacking.

Garnet-mica and staurolite-garnet-mica schists occur in places throughout the eastern belt of the Candler formation and crop out over wide areas from the vicinity of U. S. Highway 501 between Rustburg and Beaver Creek southwestward beyond the limits of the quadrangle. Garnets which vary from microscopic to 1 cm. in size, are almandite, and contain abundant inclusions of quartz, often with helicitic arrangement (Pl. 10B). Many larger crystals are cracked and replaced in part by chlorite. Staurolite commonly accompanies garnet and in many places exceeds it in amount. Fresh crystals are the exception, most having been altered partly or completely to chlorite or a mixture of chlorite, sericite, quartz, chloritoid, and iron oxides. Matrix minerals in the schists are mainly muscovite, biotite, chlorite, quartz, oligoclase, and magnetite.

A chloritoid schist phase of the Candler formation occurs at the north end of Jack Mountain and in the vicinity of Long Mountain. Chloritoid, in crystals that vary from microscopic size to porphyroblasts

1 cm. long appears to have developed partly with and partly later than the foliation (Pl. 10A). Inclusions of quartz, aligned with the foliation, are abundant. Associated minerals are chiefly quartz, sericite, and chlorite and to a less extent magnetite, martite, oligoclase, almandite, and tourmaline.

JOSHUA FORMATION

Name and occurrence.—Blue-gray schists and phyllites which overlie Candler formation and underlie Arch marble have been mapped as a unit and given the name Joshua formation, from typical exposure along Joshua Creek and its tributaries near the Campbell-Appomattox County line 3 miles northeast of Six Mile Station (Brown, 1951; 1953). Excellent exposures are also found along the Chesapeake and Ohio Railway northeast and southwest of Galts Mill, and along Opossum Creek and the Norfolk and Western Railway just east of Jack Mountain. The maximum thickness of the Joshua formation could not be determined accurately because of deformation, but it is about 1000 feet. The formation is thickest in the northwest central part of the James River synclinorium and is largely lacking along its southeast limb and in places along the west side of Jack Mountain and just southwest of Lawyer. This apparent thinning may be due either to facies change or to faulting.

Lithology.—The Joshua formation consists chiefly of hard, fine-grained, blue-gray schist with biotite porphyroblasts; but phyllite and thin beds of impure quartzite and gray marble occur locally. The Joshua formation is gradational from the Candler formation below and into the Arch marble above.

The porphyroblastic schist phase of this formation is composed chiefly of quartz, albite, muscovite, biotite, and chlorite with accessory chloritoid, almandite, clinozoisite, tourmaline, zircon, magnetite, and pyrite. The dark color is due partly to fine flakes of biotite and probably partly to finely disseminated graphite. Biotite porphyroblasts, averaging 1 mm. in length, of ragged outline, and containing abundant inclusions of quartz, have grown with random orientation across the foliation. Chlorite, in irregular to subhedral masses, is abundant and appears generally to have been of earlier development than biotite.

ARCH MARBLE

Name and relations.—The marbles of the Lynchburg area were tentatively correlated by Jonas (1928) with the Cockeysville forma-

tion of Maryland and Pennsylvania and were described under this name by Furcron (1935). At the type locality, however, Cockeysville marble underlies Wissahickon schist, whereas in this area the marbles are younger than the rocks these writers called Wissahickon and occur in several statigraphic positions. It is thus felt that use of the name Cockeysville marble should be abandoned in this area. The new name, Arch marble, has been used by the present writer (Brown, 1951; 1953) to designate those marbles which overlie Joshua schist and underlie Pelier schist. Smaller, discontinuous bodies of marble occur within the Mount Athos, Joshua, and Candler formations.

Along the eastern side of the main Slippery Creek greenstone belt, distinctions between the several marbles have been made difficult by folding, faulting, and facies change. Joshua and Pelier schists are largely absent, and marbles of both the Arch and Mount Athos types occur interbedded with quartzite and phyllite between the Candler formation and the greenstone.

Fresh exposures of Arch marble are largely confined to stream valleys. Typical exposure is found at "the Arch" on the Norfolk and Western Railway 1¼ miles east of Six Mile Station; other excellent outcrops occur along Opossum Creek southwest of Kelly and in vicinity of Flat Creek near Lawyer. Both the upper and lower limits of the formation are gradational. Thickness could not be accurately determined because of flowage, folding (Pl. 6A), and faulting, but it appears to range from about 200 to 600 feet, with an average of 400 feet.

Lithology.—The Arch formation consists chiefly of fine-grained, blue-gray, schistose marble; but medium-grained, buff to pink marble and calcareous schists and quartzites occur. Chemical analyses show calcium carbonate ranging up to 82.45%, magnesium carbornate from 2 to 15.9%, and silica from 10 to 72%. The schistose nature of the marble is due to alignment of elongated crystals of carbonate and to the presence of variable amounts of muscovite, biotite, and chlorite. Pyrite is a common constituent.

Where exposed away from streams, the marble has generally been weathered to a banded, blue, white, yellow, and pink clay containing irregular masses of calcicastic quartz.

PELIER SCHIST

Name and relations.—The Mount Athos formation as defined by Furcron (1935, pp. 22-27) includes chiefly quartzite and schist in its

middle and upper portions, but the lower 350 to 500 feet consists predominantly of schist and forms a mappable unit. In addition, the quartzite portion of the formation has commercial significance because of manganese. It is, therefore, proposed that the schist phase of the Mount Athos formation be separated and named Pelier schist, from typical exposure at the east end of Six Mile Bridge, 1¼ miles northwest of Mt. Pelier Church, 4 miles east of Lynchburg (Brown, 1953, Fig. 1). Other easily accessible exposures are along U. S. Highway 29 on the north slope of a ridge 2¼ miles southeast of City Farm.

Pelier schist is gradational from Arch marble below and is generally conformable with Mount Athos quartzite above. Locally, as at Six Mile Bridge and Mount Athos, where quartzite is based by conglomerate, a minor unconformity may separate Pelier schist from overlying quartzite.

Lithology.—Pelier schist is most characteristically a light tan to greenish gray, fine-grained, quartz-sericite schist spotted with biotite porphyroblasts. It is locally garnetiferous, and southwest of Lawyer the schist grades into gray-green phyllite. Very minor, thin, impure quartzites occur in places.

In thin section, biotite porphyroblasts show ragged outlines, abundant inclusions of quartz, and strong pleochroic halos. They are generally oriented across and are of later development than the foliation. Partial alteration to chlorite is common. Matrix minerals are chiefly sericite and fine quartz, with accessory magnetite, leucoxene, tourmaline, and zircon. Where biotite is in minor amounts or lacking, as in the phyllite phase southwest of Lawyer, fine chlorite and chloritoid are important constituents.

MOUNT ATHOS FORMATION

Name and relations.—Furcron (1935, pp. 22-27) applied the name Mount Athos[1] to the quartzites and associated schists lying between blue (Arch) marble and greenstone, as typically exposed at Mount Athos 4½ miles east of Lynchburg. In this paper, the distinctive schist phase in the lower part of Furcron's Mount Athos formation is considered a separate unit and is called Pelier schist. It is proposed to limit the name Mount Athos to those quartzites, schists, and marbles

[1] Furcron (1935, pp. 47-49 and Pl. 1) also mapped greenstones above the Mount Athos formation as Mount Athos greenstone, but described them as "Lower Greenstone Flows." The present writer has used the name Slippery Creek for these greenstones.

above Pelier schist and below Slippery Creek greenstone. The thickness of the formation as here defined ranges from about 100 to 350 feet.

Quartzite of the Mount Athos formation appears generally to rest conformably upon Pelier schist, but a minor disconformity may exist at Mount Athos and certain other places where the lower portion of the quartzite is conglomeratic. Slippery Creek volcanism began before cessation of deposition of quartzite, as shown locally by interlayered greenstone and quartzites in the upper part of the formation.

Lithology.—The Mount Athos formation consists chiefly of quartzite with variable proportions of interbedded quartz-muscovite schist; but beds and lenses of marble are commonly included. In many places, as at Mount Athos, as much as 50 feet of tan to gray, fine-grained, hematite-quartz-mica schist, of possible tuffaceous origin, lies between the uppermost beds of quartzite and the overlying greenstone.

The quartzite, nearly everywhere a ridge-maker, is light gray to brown and varies from dense to conglomeratic, and from highly siliceous to strongly micaceous or calcareous. Some pale blue quartz grains or pebbles are generally visible. Thin sections show small quantities of microcline and plagioclase and the invariable presence of some well-oriented muscovite. The quartz grains vary from partly recrystallized with strong strain shadows to completely recrystallized without appreciable shadows.

Calcareous quartzite, in places, grades into siliceous, micaceous, or relatively pure white, blue-gray, and pink, medium- to coarse-grained marble. Lenticular bodies of Mount Athos marble occur sporadically in the central part of the synclinorium; much more continuous bodies, some from 200 to 300 feet thick, always associated with quartzite, are very common along the southeast side of the main Slippery Creek greenstone belt, particularly in vicinity of Beaver Creek and Smith Branch. In many of these southeastern occurrences, however, facies change and strong deformation have made it difficult or impossible to determine which marbles should be called Arch and which Mount Athos.

Detailed studies of manganese in this region by Espenshade (1954) have shown that commercial accumulations are associated exclusively with the Mount Athos formation. The porous residuum resulting from weathering of calcareous quartzite almost everywhere shows impregnations of manganese oxides; and the marble commonly weathers to soft, sandy, micaceous brown to black wad. Nodular, psilomelane-

type ore has been produced chiefly from seams of clay, chert, or decomposed rock between quartzite and schist or marble (Espenshade, 1954, pp. 55-58).

SLIPPERY CREEK GREENSTONE

Name and relations.—Slippery Creek greenstone (Brown, 1951; 1953, Fig. 1 and p. 93), typically exposed along Slippery Creek 5 miles east of Lynchburg, overlies Mount Athos formation and is the youngest metamorphic rock in the area. Furcron (1935, pp. 47-49 and Pl. 1) described these rocks as "Lower Greenstone flows," lying beneath the Mount Athos formation, but mapped them as "Mount Athos greenstone." The new name is here used because they are the upper greenstones in the area, not the "lower," and they represent a mappable unit distinct from the Mount Athos formation.

Slippery Creek greenstone, with its amygdaloidal phases and definite stratigraphic position, appears to represent a series of lava flows; its composition and association with geosynclinal sediments suggest that it is spilitic. Maximum thickness is unknown but it is probably in excess of 1000 feet. Quartzite is locally interlayered with the lower flows of the series, showing that volcanism began before cessation of Mount Athos quartzite deposition. Certain mica schists, mapped by the writer as the upper part of the Mount Athos formation, may be tuffaceous and related to this volcanism.

This greenstone is exposed chiefly in a belt from one to two miles wide, referred to in this paper as the "main greenstone belt," which extends northeastward completely across the south central part of the quadrangle. Within this belt, strips of older rocks have been brought to view by thrust faults. Smaller tongues of greenstone occur in the Jack and Round Mountain synclines and in small klippe west of the main greenstone belt.

Lithology.—The Slippery Creek greenstone is dark gray-green, blue-green, to yellow-green, fine-grained, and more or less schistose or gneissose. Weathering reduces the rock to light reddish-brown, soft, porous plates and masses. Amygdaloidal facies occur but are nowhere widespread. Visible minerals in usual order of abundance include actinolite, biotite, feldspar, epidote, and chlorite. Feldspar is generally granular and glassy. Coarse flakes of biotite and blades of actinolite commonly coat cleavage surfaces.

Thin-sections show a confused array of secondary monerals imposed upon a background of stubby, subhedral crystals of well-twinned

albite (Table 4). Amphibole, usually actinolite, is plentiful in all but the more siliceous facies. Epidote is abundant in all slides examined and, with quartz, forms a common yellow-green epidosite facies. In amygdules, it occurs in coarse crystals with quartz, albite, and actinolite. Porphyroblasts of green-brown biotite, abundant in some sections, have ragged outlines and many inclusions and are generally oriented with the foliation. Both amphibole and biotite show alteration to chlorite.

SILL- AND DIKE-LIKE ROCKS

GENERAL STATEMENT

Sill- and dike-like rocks of this area consist of: 1) hornblende-plagioclase amphibolite and gneiss, 2) an ultrabasic association of rocks, and 3) Triassic (?) diabase. The first, if the writer's interpretations are correct, includes rocks of at least two widely separated ages: 1) hornblende gneiss of Reusens migmatite which appears to be distinctly older than the Marshall-like leuco-gneiss of the Reusens migmatite, and 2) similar hornblende-rich rocks within and apparently younger than Lynchburg formation. The only known distinctive characteristics of Reusens hornblende gneiss are its migmatitic form and association with Marshall-like gneiss of igneous aspect. Hornblende gneiss lacking these characteristics was mapped as post-Reusens, but it is very probable that some of this rock is actually the older gneiss.

Rocks of the ultrabasic association occur in the Lynchburg formation and older rocks and are commonly associated with the much more abundant hornblendic rocks but, for the most part, appear to be quite distinct from them. Neither the ultrabasics nor the hornblendic rocks have been observed in rocks younger than Catoctin greenstone.

POST-REUSENS HORNBLENDIC ROCKS

Occurrence and origin.—Hornblende-rich rocks, in sill-like bodies from a few inches to several hundred feet thick and a mile or more long, occur here and there in most parts of the Lynchburg formation and are particularly abundant within and just north and west of the city of Lynchburg. Although most workers have called these rocks hornblende gabbro or metagabbro (Burfoot, 1930; Pegau, 1932; Hess, 1933; Furcron, 1935; Bloomer and Werner, 1955), the question of origin is not completely settled. Chemical data so necessary in solving such questions are lacking; but features of hornblendic rocks in Lynch-

burg formation of the Lynchburg area which are suggestive of origin, and which must be explained in any theory of origin, include:

1. The mineral content of the hornblendic rocks indicates a chemical composition similar to that of basic igneous rocks (see Table 6 and Barth, 1952, p. 28); also, it is known that any of the minerals of these rocks can form from those of basic igneous rocks.

2. The bodies occur prevailingly concordant with bedding, interlayered and intertongued with metasedimentary schists and gneisses of the Lynchburg formation. Minor cross-cutting occurs along borders of some masses (Fig. 4), but definite cross-trending, dike-like bodies have not been observed.

3. Contacts with metasedimentary gneiss of the Lynchburg formation are commonly distinctly gradational, with hornblende and

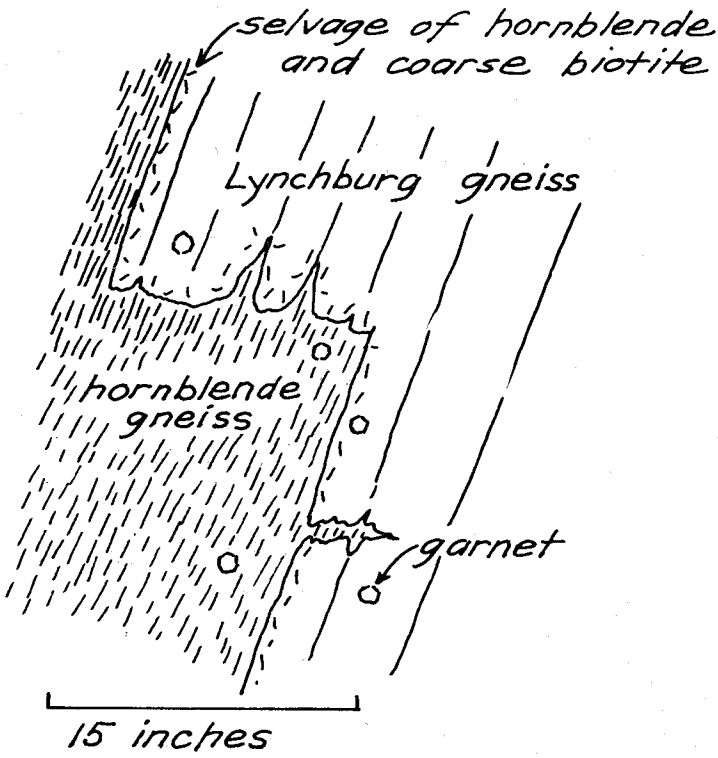


FIGURE 4.—Sketch of cross-cutting relationship at contact between hornblende gneiss and Lynchburg formation (gneiss) half a mile west of Madison Heights.

feldspar of the mafics gradually giving way to biotite and quartz of the Lynchburg formation.

4. Lens- and pod-like zones, frequently rich in garnet, intermediate in composition between the mafics and normal Lynchburg, always with gradational borders, occur as apparent "spot" alterations in the Lynchburg formation.

5. Veins and pods of coarse white marble from a fraction of an inch to a foot thick occur within some hornblendic bodies.

6. Textures in the hornblendic rocks appear to be largely or wholly crystalloblastic.

It is difficult to determine whether the hornblendic rocks are metaigneous or metasedimentary. Origin as basic igneous material in the form of intrusives, lavas, or tuffs is strongly favored by mineralogic composition, but some features favor and some oppose each possible form. General concordance and lack of definite dikes make an intrusive origin appear unlikely; but gradation and minor cross-cutting at the borders of bodies could be contact effects. Masses with gradational borders could hardly be flows but could be tuffaceous sediment, although the sparsity of quartz and mica within the hornblendic bodies opposes much mixing of tuff and sediment. Bodies with cross-cutting at the borders could not be tuff unless there were considerable later redistribution of material. The one origin which appears best to fit all known characteristics of these hornblendic rocks in the Lynchburg formation in this area, and the one favored by the writer, is metasomatism, perhaps of calcareous or dolomitic zones within the Lynchburg formation. Admittedly, although unhornblendized zones of this sort do occur in the Lynchburg formation, they are rare; also, hornblendic bodies in this area either lack quartz and mica or are poorer in these minerals than are most such rocks elsewhere which have been interpreted as metasediments. These factors, which do not rule out metasomatism, however, appear to be counterbalanced by border characteristics and mode of occurrence.

Plagioclase amphibolite.—This name, following Tyrrell (1929, p. 311), is applied here to hornblendic rocks composed chiefly of amphibole and plagioclase and having a granoblastic rather than foliated structure. These rocks are dark greenish gray to black and medium to coarse grained. Approximate modes are given in Table 6. Hornblende occurs in rough, unoriented, stubby crystals from ⅛ to ¾ inch long, either closely intergrown or as discrete, often lenticular porphyroblasts enclosed in white, glassy, granular feldspar. Under

the microscope, the hornblende is seen to be mildly to strongly pleochroic in various shades of green and yellowish green. Small crystals are commonly euhedral; some larger ones have a shredded appearance, and sieve structure is frequent. Plagioclase (andesine), and in places sparse quartz, form the inclusions in the latter and occur in aplitic aggregation between hornblende crystals. Much plagioclase is untwinned, but albite twinning and progressive zoning are common. Almandite garnet is locally prominent and red-brown biotite, although not a usual constituent, is plentiful in places. Interstitial calcite is fairly common and here and there forms veins up to several inches thick cross-cutting foliation.

Hornblende gneiss.—This rock has essentially the same composition as the plagioclase amphibolite but is usually finer grained and has a distinct linear foliation due to alignment of elongate hornblende crystals. The two types are closely associated and frequently grade one into the other.

ULTRABASIC ASSOCIATION OF ROCKS

General statement.—A group of closely associated ultrabasic with minor basic rocks occurs in Lynchburg formation and Moneta gneiss of this region. Chief members of this group, in approximate order of abundance, are: amphibole-chlorite schist ("metapyroxenite"), serpentinite, soapstone, and peridotite. These rocks are interlayered and grade one into another. Although they are commonly associated with the more abundant hornblendic rocks just described, they are quite distinct both in petrology and occurrence. The ultrabasic association includes only very minor and local feldspathic portions, whereas the hornblendic rocks everywhere contain some feldspar and, in this writer's experience, never grade into rocks of the ultrabasic association. Both show prevailing concordance with bedding of enclosing rocks, but the ultrabasics typically show much greater linear extent or tendency to occur along certain structural or stratigraphic trends, suggestive either of a deep tectonic control or a surficial origin. The most noteworthy localization of rocks of the ultrabasic association in this region is near the top of the Lynchburg formation, often in close association with Catoctin greenstone.

The ultrabasic association of the Lynchburg area is essentially a continuation of the Albemarle-Nelson counties belt (Watson, 1907, pp. 293-296) which includes the great serpentine-soapstone deposits of

TABLE 6.—*Approximate modes of hornblendic rocks and rocks of the ultrabasic association*

	Amphibolite and Hornblende Gneiss					Ultrabasic Association								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Plagioclase	58	22	52	55	36	.....	.....	.....	.....	.....	.....	.....	.....	.....
Pyroxene	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	5	.....	.....	.....
Hornblende	40	65	45	38	62	.....	.....	.....	.....	.....	.....	.....	.....	.....
Tremolite-actinolite	.....	.....	.....	.....	.....	40	35	35	70	80	20	3	.....	80
Quartz	.....	8	x	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Olivine	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	15	.....	.....	.....
Biotite	.....	x	.....	7	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Phlogopite	.....	.....	.....	.....	.....	.....	.....	.....	4	5	.....	.....	.....	.....
Iddingsite	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1	.....	.....	.....
Chlorite	x	2	.....	.....	.....	59	57	65	25	3	43	15	15	19
Serpentine	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	15	75	10	.....
Talc	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	5	64	.....
Carbonate	.....	1	.....	.....	.....	.....	6	.....	.....	.....	x	.....	10	.....
Clinozoisite	.....	.....	2	.....	.....	.....	.....	.....	.....	12	.....	.....	.....	.....
Sphene	.....	.....	1	x	2	.....	.....	.....	x	.....	.....	.....	.....	x
Apatite	x	.....	.....	x	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Garnet	x	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Magnetite-ilmenite	2	2	.....	.....	.....	1	1	x	.....	.....	1	2	x	x

Pyrite	.....	.....	.....	.....	.....	.....	½	.....	x	x	.....	.....	x	x
Pyrrhotite	.....	.....	.....	.....	.....	.....	½	.....	x	x	.....	.....	x	x
Percent anorthite in plagioclase	32	35	38	30	40	.....	.....	.....	.....	.....	.....	.....	.....	.....

x Present in less than ½ percent.
1. Hornblende gneiss, Amherst County, 200 feet north of 7th Street James River bridge.
2. Hornblende gneiss, ½ mile north of No. 1.
3. Plagioclase amphibolite, Fort Ave., near Twelfth Street, Lynchburg.
4. Biotite-hornblende gneiss, U.S. Hwy. 501, 1½ miles west of Lynchburg.
5. Plagioclase amphibolite, Norfolk and Western Railway at State Road 297, 2 miles west of Lynchburg.
6. Actinolite-chlorite schist, Virginia Greenstone Co. quarry, Lynchburg.
7. Tremolite-chlorite schist, Virginia Greenstone Co. quarry, Lynchburg.
8. Porphyroblastic tremolite-chlorite schist, 1½ miles southwest of Lynchburg.
9. Chlorite amphibolite, 1½ miles southwest of Lynchburg.
10. Amphibolite, 1½ miles southwest of Lynchburg.
11. Metaperidotite, 1½ miles southwest of Lynchburg.
12. Serpentinite, 2 miles northwest of Round Mountain, Amherst County.
13. Soapstone, 2 miles northwest of Round Mountain, Amherst County.
14. Chlorite amphibolite, 1½ miles southwest of Lynchburg.

Schuyler, Virginia. Members of the association in this area, although differing in relative proportion and in size of body, are very similar to those at Schuyler, the nature and origin of which have been discussed by Burfoot (1930) and Hess (1933).

Ultrabasics of this region also lie within the belt of ultramafics which follows the northwest edge of the inner zone of the Appala-

TABLE 7.—*Chemical analyses of chlorite-amphibole schist of the ultrabasic association. (All analyses were made for the Virginia Greenstone Company. No. 1 made by Robb & Moody, and Nos. 2 and 3 by Froehling & Robertson, Inc., both of Richmond, Virginia.)*

	1	2	3
Silica	42.84	40.19	46.58
Iron oxide	7.77	13.48	8.34
Al_2O_3	20.47	7.51	13.48
CaO	7.02	4.52	14.33
MgO	16.19	29.79	14.63
Sulphur	.53	.....	.....
Loss on ignition	4.82	4.43	0.43
Moisture	.....	0.16	0.10

1. "Virginia Greenstone," green stock, from Virginia Greenstone Company Daniel Avenue quarry, Lynchburg (Table 6, No. 6).
2. Chlorite amphibolite, 1½ miles southwest of Lynchburg (Table 6, No. 14).
3. Amphibolite, 1½ miles southwest of Lynchburg (Table 6, No. 10).

chians from Alabama to Gaspe Peninsula (Pratt and Lewis, 1905, pp. 34-35; Hess, 1955, p. 396). On the basis of location within this belt, great linear extent, and relatively high magnesian content (Table 7) these bodies could belong to the orogenic, or "alpine" ultramafic association (Benson, 1926, p. 6). In most alpine associations, however, peridotites and serpentinites greatly predominate over other rock types (Turner and Verhoogen, 1951, p. 242; Hess, 1955, p. 393); in the general region from south of Lynchburg to Charlottesville these are common, but actinolite amphibolites and actinolite-chlorite schists are the most characteristic types. In alpine suites, feldspathic rocks are absent or sparse; in the ultrabasic association of this region, feldspathic rocks are also rare, but the alumina content in actinolite-rich facies suggests that these originally may have been feldspathic (Hess, 1933, p. 382). Both of these differences might be explained in Turner's and Verhoogen's (1951, p. 495) statement that "At higher temperatures, ultrabasic rocks that originally contain CaO, or are exposed to lime-

bearing solutions, tend to give actinolite rock or (if Al_2O_3 is present) actinolite-chlorite rock instead of serpentine, as products of hydrothermal metamorphism." More difficult to explain, however, might be the lack or sparsity in ultrabasics of this region of accessory chromite, which Hess (1955, p. 394) says "is present in practically every thin section cut of an alphine ultramafic."

An important feature in the occurrence of rocks of the ultrabasic association of this region is their frequent localization near the top of the Lynchburg formation, commonly in close association with Catoctin greenstone, and apparent absence in rocks younger than Lynchburg and Catoctin. In the belt of Lynchburg formation on the west flank of the James River synclinorium, this localization could be due to fracturing along the axis of downwarp into this synclinorium—but such an explanation would not be so readily applicable to the same localization and association in the upper Lynchburg formation of domes further east, including those near Altavista (Espenshade, 1954, Pl. 1), the Sherwill anticline, and the large Hardware anticline west of Arvonia (Fig. 1). A possible, quite different explanation could be that the soapstone and related rocks near the top of the Lynchburg are altered lavas, rather than plutonics, perhaps altered picrites as suggested by Hess (1933), or even extrusive ultramafics as suggested by Bailey and McCallien (1953, p. 421) for serpentine in Turkey. This could explain their stratigraphic localization regardless of structural position; also their concordance with bedding, and association with Catoctin extrusives but failure to penetrate rocks which in this area seem to lie conformably above. Under this hypothesis, ultrabasics lower in the Lynchburg formation and in pre-Lynchburg rocks could be wholly or largely intrusive; also, the age of the ultrabasic association of this western Piedmont belt must be near, or at least no younger than that of the late Precambrian or early Cambrian Catoctin greenstone.

Ultrabasic bodies in this area range from about 10 to 700 feet thick and from a few hundred yards to over 5 miles long. Large masses, however, when diamond drilled, generally turn out to be composite, consisting of numerous distinct types and intergradations; even where dominantly of one type, masses usually consist of several discrete bodies, most of which are not over 50 feet thick. Some masses have only faint foliation, some possibly none; but foliation is generally distinct, and parts of many masses are highly schistose.

Amphibole-chlorite schist.—Actinolite-chlorite and tremolite-chlorite schists, commonly accompanied by lesser amounts of other members of the ultrabasic association, occur in numerous places within the northwestern belt of Lynchburg formation (Pl. 1). They are more or less resistant to erosion and, therefore, tend to form hills and to outcrop as "ledges" and "whalebacks." The largest bodies are: 1½ miles northwest of Round Mountain, just west of U.S. Highway 29 a mile southwest of Lynchburg, and within and extending southwestward from the Fort Hill section of the city of Lynchburg. The latter is of particular interest in that it is from this body that "Virginia Greenstone," a beautiful and valuable stone, has been quarried for many years.

These schists are essentially the same as the "metapyroxenites" described by other workers (Burfoot, 1930, pp. 810-817; Pegau, 1932, pp. 27-29). They are pale to dark green, medium to coarsely crystalline, frequently porphyroblastic, and massive to highly schistose. The color is determined chiefly by that of the amphibole and by the percentage of chlorite present. Phases rich in chlorite are the most schistose; some amphibole-rich phases have decussate structure and are outwardly almost massive. In the porphyroblastic phases, aggregates and single crystals of amphibole, one-eighth to three-fourths inch long, occur amid plates of chlorite and interlacing needles of tremolite-actinolite. Under the microscope, these porphyroblasts have a fragmented to shredded appearance, particularly on the ends extending into the cleavage. Phlogopite, magnetite, and pyrrhotite are common accessories.

"Virginia Greenstone" has the fortuitous combination of rich dark green actinolite and chlorite, large porphyroblasts which give the stone a desirable "bold pattern," with enough chlorite to make the stone easily workable and enough needle-like actinolite to make the stone strong and nearly massive. For a further discussion of this stone, see under Mineral Resources.

Peridotite.—Peridotite occurs interlayered with other ultrabasics at a place a mile southwest of Lynchburg and at another 1½ mile northwest of Round Mountain (Pl. 1). It is dark gray to bluish gray, fine- to medium-grained, and commonly contains megascopic ragged flakes of chlorite and greenish-brown crystals of olivine and pyroxene. Thin sections show rounded olivine crystals from 0.15 to 1.0 mm. across in a field of chlorite, tremolite, and serpentine. Olivine frequently has a corona of tremolite, often with an intermediate corona

of chlorite and serpentine; in some less altered portions of the rock it is enclosed in large crystals of pyroxene (pigeonite?) including fine, more or less aligned grains of magnetite. Iddingsite, as an alteration of olivine, and carbonate occur in all slides examined. Paragenesis appears to have been: (1) olivine, (2) pyroxene, (3) tremolite replacing olivine and to a lesser extent pyroxene, (4) chlorite replacing pyroxene and to some extent tremolite and olivine, and (5) serpentine replacing chlorite and earlier minerals.

Serpentinite.—This rock, composed predominantly of serpentine and containing little olivine or talc, is dark gray, bluish gray, or grayish green and fine to medium grained. Thin sections show chiefly serpentine in tiny cross-fiber veinlets and felted masses including irregular patches of chlorite and partly replaced tremolite. The shape of the chlorite masses suggests that it formed from an interstitial mineral, probably pyroxene or secondary amphibole; and that the serpentine formed chiefly from a mineral of rounded outline, probably olivine. Talc, in flakes and masses of variable size, appears to have replaced serpentine.

Soapstone.—This rock, found chiefly in the belt of ultrabasics west and northwest of Round Mountain, is usually medium green gray to yellowish green, medium-grained, and has a slick feel because of abundant talc. Ankerite is generally present in crystals and masses from 2 to 10 mm. across which, at the surface, weather out to give what the quarrymen call "nail hole." Thin sections show talc in masses and ragged flakes of random orientation to be intimately mixed with fine serpentine, chlorite, and carbonate. This fine chlorite is weakly pleochroic from colorless to pale green; pennine, in coarse flakes and masses, with tan to pale green pleochroism, also occurs. Opaque minerals include pyrite, pyrrhotite, and magnetite.

TRIASSIC DIABASE

Although Triassic diabase is common in nearby portions of the Piedmont, only one small dike in the northeast corner of the quadrangle was observed in this area. This rock, essentially similar to Triassic diabase in other parts of the Piedmont (Roberts, 1928, pp. 42-62), weathers into spheroidal masses, is medium- to fine-grained, and dark gray to black. The microscope shows abundant euhedral laths of labradorite partly enclosed in anhedral augite and the interspaces filled with quartz-orthoclase micropegmatite. Magnetite, secondary hornblende, and biotite also occur.

AGE OF ROCKS

No fossils have been found in the rocks of the Lynchburg area, so ages, for the most part, can only be approximated. Radioactive age determinations on allanite from pegmatite associated with the Pedlar formation in northern Amherst County gave an average figure of 860 million years (Marble, 1935, p. 351). If the Marshall gneiss was produced by the same magmatic and/or granitizing processes which produced rocks of the Pedlar formation, as postulated, it is of similar age unless we class it strictly as a metamorphic rock, in which case its age is that of the parent rock (Bloomer, 1950, p. 760). The Moneta gneiss, granitized in part in the development of the Pedlar formation and the Marshall gneiss, is possibly early Precambrian. The Lynchburg formation, which unconformably overlies the Virginia Blue Ridge complex and underlies the Catoctin greenstone, is probably correlative in part with the Swift Run formation with these same relations in the Blue Ridge (Jonas and Stose, 1939). Bloomer and Bloomer (1947, pp. 102-106) would place the Swift Run formation and Catoctin greenstone in the lower Cambrian, but Jonas and Stose (1939, p. 590) and King (1949, pp. 536-538) consider that they belong in the upper Precambrian.

The fact that volcanics of the Catoctin period of activity occur in the lower parts of both the Candler formation and the Chilhowee group of the Blue Ridge (Bloomer, 1950, pp. 775-778) strongly suggests that the Candler formation is at least partly equivalent to the lower Chilhowee group, which is considered by many geologists to be lower Cambrian in age.

The Arvonia slate, which is of known upper Ordovician age (Watson and Powell, 1911) and which occurs in the north central Piedmont, is lithologically similar to portions of the Candler formation, particularly its Esmont slate facies, and also lies, in part, upon probable Catoctin greenstone (Brown and Sunderman, 1954). A relationship between the Arvonia slate and the Candler slate is thus suggested, but greenstones within the Arvonia slate are unknown and there may be appreciable unconformity between the Arvonia slate and the underlying greenstones (see Fig. 3).

The phyllite facies of the Candler formation in this area is continuous northeastward along the strike into slates and phyllites, designated as Loudoun in age on the Geologic Map of Virginia (1928), which appear to underlie gray slaty Everona limestone and its associated thin quartzites. Jonas (1927, pp. 842-843) found in these

quartzites imperfect fossils from which an exact age could not be determined; but she tentatively correlated the associated Everona limestone with the Frederick limestone of upper Cambrian age in Maryland. It is probable that the Arch marble of the Lynchburg area, because of its lithologic similarity and similar stratigraphic position above the Candler, is more or less equivalent to the Everona and may also be of upper Cambrian age.

Slippery Creek volcanics, stratigraphically above the Arch marble, seemingly must be no older than upper Cambrian. The moderate thickness of sediments and the lack of large unconformities between these volcanics and the Arch marble suggest that they are no younger than Ordovician.

STRUCTURE

GENERAL STATEMENT

Portions of three major structural features included within the Lynchburg quadrangle are, from northwest to southeast: the Catoctin-Blue Ridge anticlinorium, the James River synclinorium, and the Sherwill anticline. In addition, Jonas (1932, Pl. I) has mapped the contact between phyllitic Candler formation and Lynchburg formation (or intervening Catoctin greenstone) as the Martic overthrust. In this contact surface, which dips beneath rocks of the Evington group in the James River synclinorium and is exposed on both flanks of this synclinorium, is a major thrust surface as conceived by Jonas, the Lynchburg formation and related rocks in the Sherwill anticline lie in a fenster. Certain evidences, however, (see Martic line) oppose the existence of a major overthrust and favor a normal stratigraphic sequence.

CATOCTIN-BLUE RIDGE ANTICLINORIUM

Core rocks of this anticlinorium, consisting of Pedlar formation grading southeastward into Marshall gneiss, and the Marshall gneiss along its southeast border fingering into the Reusens migmatite, occupy a belt five miles wide in the northwest corner of the quadrangle. Gneissic structures in these rocks have a prevailing northeast strike and steep southeast dip. Northeasterly trending schist bands, which are common in the Marshall gneiss, appear, in places, to mark shear zones; elsewhere they may be ungranitized remnants of older rocks (Bloomer and Werner, 1955, p. 581).

Lynchburg formation, in a northeasterly trending belt five miles wide, overlies unconformably these core rocks of the anticlinorium and flanks them on the southeast. Bedding in the Lynchburg formation nearly everywhere dips steeply to the southeast; but at least three anticlinal folds, all asymmetric to the northwest, have been mapped along James River (Fig. 5). The easternmost of these, the Lynchburg anticline, is readily visible in the bluffs opposite the city of Lynchburg (Pl. 3A), but the other two were delineated chiefly by bedding-cleavage relations. In these structures, massive beds have undergone flexure folding, while intervening schistose beds have folded by shear. If important intraformational faults exist in the Lynchburg formation, they are not readily evident because of the lack of mappable subdivisions.

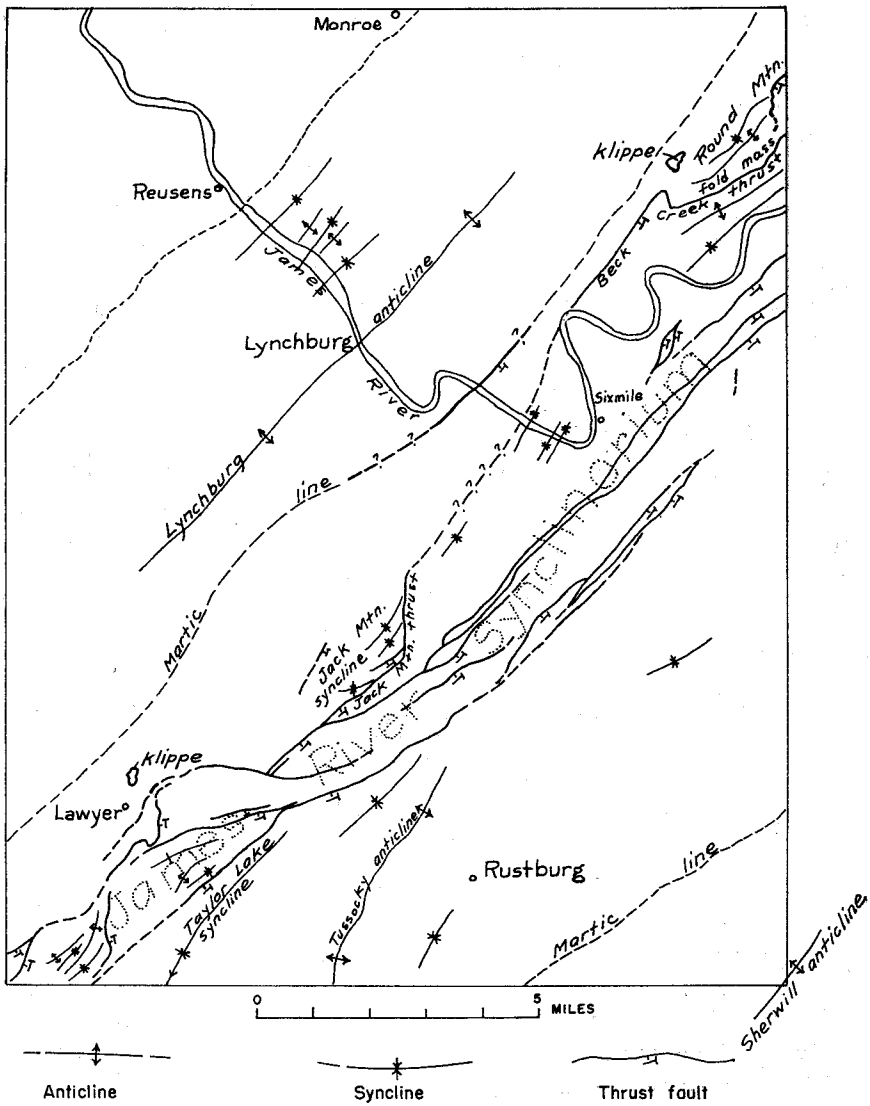


FIGURE 5.—Index map of structures in the Lynchburg quadrangle, Virginia.

JAMES RIVER SYNCLINORIUM

The James River synclinorium (Brown, 1953) in Virginia parallels and lies just southeast of the Catoctin-Blue Ridge anticlinorium from

Orange County southwestward to the North Carolina line near Stuart in Patrick County, a distance of 200 miles. It is one of the several such belts of infolded surficial rocks of relatively low metamorphic grade, referred to by King (1955, p. 350) as "dejective zones," which characterize parts of the inner zone of the central and southern Appalachian system.

This synclinorium trends northeastward across the central part of the Lynchburg quadrangle, limited on the northwest by the Blue Ridge uplift and on the southeast by the Sherwill anticline. The Evington group of rocks, younger than the Lynchburg formation exposed in the bordering structures, has been preserved in this downfold. Bedding, where visible, and cleavage generally dip steeply southeastward in the northwestern and central parts of the synclinorium, but most commonly dip north to northwest in the southeastern part. In the central part of the synclinorium, thrust faults are so numerous as to have produced a general imbricate structure. Although faults may be equally numerous in the bordering areas, they are not discernible because of the thickness of the stratigraphic units involved. Isoclinal folding has occurred within the synclinorium and is most prominent on the flanks. Both folds and faults have been mapped almost entirely upon the basis of stratigraphy.

Thrust faults are prevailingly high angle, either because of rotation during close squeezing of the synclinorium or because of initiation during the squeezing process after the stress had attained a large vertical component. Some high-angle thrusts may be upward branches from lower-angle thrusts of greater displacement which emerge along the northwestern part of the highly faulted zone (Pl. 1).

Outstanding among the lower-angle thrusts is the Beck Creek fault, in the northeastern part of the quadrangle, which wraps around the southeast side of the complex Round Mountain fold mass and once extended beyond, as indicated by a klippe west of Round Mountain (Fig. 5). The low-angle thrust at Jack Mountain, about 5 miles south of Lynchburg, which has cut off the northeast end of the Jack Mountain syncline, may be a continuation of the Beck Creek thrust, but no connection has been successfully mapped through the intervening area of Candler formation. Low-angle faulting seems also to have occurred within the main Slippery Creek greenstone belt south of Lawyer in the southwest part of the quadrangle, where the north end of a complex quartzite-marble anticline has been overridden by greenstone.

The structure along the southeast side of the main Slippery Creek

greenstone belt where Candler formation emerges from beneath this belt has been complicated by facies changes and the presence of greenstones older than the main body of Slippery Creek volcanics. Faulting has occurred in numerous places, but the near continuous occurrence of relatively thin marbles and quartzites seems to indicate that lateral displacement has not generally been great.

SHERWILL ANTICLINE

In this area, the James River synclinorium is bordered on the southeast by the Sherwill anticline which, in turn, is bordered on the southeast by the Danville Triassic basin (Brown, 1953, Pl. 1). In this anticline, Lynchburg formation is exposed in a belt 23 miles long between Otter River just northeast of Altavista and Spout Spring 13 miles southeast of Lynchburg. Catoctin or Catoctin-like greenstones in the lower part of the Candler formation and lying between the Candler formation and Lynchburg formation occur along the northwestern limb and partly wrap the plunging northeast end of the anticline.

The crest of the Sherwill anticline extends northeastward across the southeastern tip of the Lynchburg quadrangle and, in the southeastern corner of this quadrangle, Lynchburg formation on the northwest limb forms a belt 2½ miles wide. Bedding in this part of the northwest limb dips from vertical to 65° NW.; from the crest southeastward to the Triassic border fault, 2 miles from the quadrangle, it has relatively low dips.

MARTIC LINE

Jonas (1929, pp. 508-509; 1932, pp. 36-37) interpreted belts of rocks of relatively low metamorphic grade in the southern Appalachians, lying between areas of higher-grade rocks, to be zones of mylonitization resulting from large-scale overthrusting, rather than belts of Cambrian rocks lying within Precambrian as previously interpreted (Geologic Map of Virginia, 1916; Keith, 1905, p. 5, 1907, p. 4; Keith and Sterrett, 1931, pp. 5-6; et al.). Retrogressive metamorphism associated with overthrusting is considered to have reduced these rocks, once of higher grade, to their present low-grade condition. On this basis, in Virginia, she concludes that the western outcrop belt of the Candler formation (her albite-chlorite schist facies of the Wissahickon), extending from Orange County 200 miles southwestward to the North Carolina line near Stuart in Patrick County, is

a zone of diaphthoresis and phyllonitization marking the southwestward continuation of the Martic overthrust as mapped in southeast Pennsylvania (Knopf and Jonas, 1929). According to her (Jonas, 1932, p. 33), the Martic thrust block was driven westward for 15 or 20 miles as a great nappe over rocks of the Catoctin-Blue Ridge anticlinorium. In view of the uncertainty of these conclusions, the western border of the phyllitic part of the Candler formation, mapped as the border of the Martic thrust block, is referred to in this paper as the Martic line.

In Jonas' (1928; 1929, pp. 507-508) earlier interpretations, presumably to explain the nearly straight extent of the Martic line, she considered the overthrust surface southwest of Albemarle County down-dropped from view by normal faults; later she (Jonas, 1932, p. 33) states that it is down-dropped northeast of Lynchburg but is at the surface to the southwest. Furcron (1935, p. 52 and Pl. 1) apparently accepts her views in principle but shows the thrust surface normal-faulted from view the extent of his map from south of Lynchburg into Albemarle County.

It is the writer's opinion that the very long, narrow belt of phyllitic rocks occupied by the Candler and other formations of the Evington group is not a zone of phyllonitization along a major overthrust but is primarily a relatively tight, deep synclinal infold of younger rocks resting, for the most part, against adjacent older rocks in normal stratigraphic succession. Some movement has doubtless been localized in the fissile Candler phyllite, but it is thought that the Martic line in Virginia does not generally mark an important fault. Bloomer (1950, pp. 764-765) is of similar opinion; and Espenshade (1954, pp. 34-35 and Pl. 1), although mapping his Candler-Lynchburg contact as a fault, states that the fault movement may have been relatively slight.

The concept of a Martic overthrust in Virginia is based largely upon the interpretation that chlorite-muscovite schists and phyllites of the Candler formation (Jonas' Wissahickon) were once of higher metamorphic grade, like Lynchburg formation to the northwest and parts of the Candler formation a mile or so to the southeast, but that they have been retrogressed by stress associated with overthrusting (Jonas, 1932, pp. 7-11; Furcron, 1935, p. 55). It appears highly improbable, however, that retrogression could have been so complete and extensive as to have produced so large and relatively uniform a unit as the Candler formation. Southwestward, phyllite of the Candler formation generally grades into schists containing biotite, then garnet

and, locally, staurolite; but it seems that distinctive remnants of partly retrogressed higher-grade rock should be common within the belt of phyllite. Such remnants have not been observed. Zones containing porphyroblastic biotite, garnet, and chloritoid occur within the main phyllite belt; but, in the specimens studied, these minerals are younger than the phyllitic foliation which is supposed to have developed with or after mylonitization (Pls. 10A and 10B).

The partial alteration of biotite and garnet to chlorite and of staurolite to chlorite or chloritoid, commonly found in higher-grade Candler formation on the southeast side of the James River synclinorium, have been interpreted as incomplete retrogressive effects related to the more complete retrogression nearer the thrust surface to the northwest. Such alterations are retrograde in the sense that lower temperature minerals have taken the place of higher, and they may well be promoted by deformation; but, as pointed out by Billings (1937, p. 552), they are not necessarily related to major faulting or other special structure. The fact that so many of the alterations cited as typically retrograde require the addition of water has led Schwartz and Todd (1941) and Hietanen (Cloos and Hietanen, 1941, pp. 135-136) to the conclusion that they are often hydrothermal rather than truly retrogressive.

In the Lynchburg area, bedding in the Candler formation is rarely observed except as occasional quartzitic layers; but northeast of this area where metamorphism has been less intense, beyond Nelson County, bedding is rather commonly preserved. Near Lynchburg, too, bedding is beautifully preserved in parts of each of the other members of the Evington group, and these, as well as the Candler formation, form part of the belt of phyllitic rocks between higher grade metamorphics. Rocks that have been raised to middle or high metamorphic grade, then milled out and retrogressed to the point that all vestiges of the earlier high-grade metamorphism have been destroyed could hardly retain their bedding. Mrs. Stose (formerly Miss Jonas) has suggested, in personal communication, that only the Candler belongs to the thrust block, and these well-bedded members of the Evington group are younger rocks lying in fensters. The often-repeated sequence: Candler, Joshua, Arch, etc. and the perfect gradation between Candler and Joshua formations, however, seem to rule out this possibility.

Probably the strongest evidence against large-scale faulting of any type at the base of the Candler formation is the very widespread oc-

currence of Catoctin or Catoctin-like greenstones at or near the Candler-Lynchburg contact and the way in which the Catoctin greenstone transgresses this contact. The general stratigraphic sequence; Lynchburg formation, Catoctin greenstone, Candler formation is found, not only in most places along the Martic line from Orange County to Patrick County, but at least partly about all of the known domes (fensters under the thrust hypothesis) which expose Lynchburg gneiss southeast of the Martic line. These domes include: the Sherwill anticline, previously described; a sizeable dome one mile west and another 4 miles west of Altavista (Espenshade, 1954, Pl. 1); the Tussocky dome 1½ miles northwest of Rustburg. It is inconceivable that the sole of a great thrust could be in contact or near-contact with the same, often thin, stratigraphic unit at practically every exposure in fensters and along its front for a distance of nearly 200 miles.

The feature in the Lynchburg vicinity which most favors the hypothesis that the Martic line is a fault in the usual rather abrupt change in lithology and metamorphic grade at or near this line. Strong lithologic change commonly occurs within a thickness of a few feet, but there are places where the change is gradational over a zone of 1000 feet or more. Possibly, the places of most abrupt change are marked by unconformity or local faulting, but the zones of gradation scarcely suggest either. Furthermore, considering that equally or more abrupt lithologic changes due entirely to normal sedimentary or erosional processes are common in areas of unmetamorphosed rocks, it would seem reasonable to suppose that these changes at the Martic line might also be the result of such processes. The change in metamorphic grade in the vicinity of the Martic line is more difficult to explain. It should be noted, though, that this change is not everywhere so marked as it is in the Lynchburg area. Near Lynchburg, chlorite grade Candler phyllite is adjacent to biotite and biotite-almandite Lynchburg schist and gneiss. In places northeast of this area, where metamorphism has been less intense, rocks of the chlorite facies occur above and below the Martic line; similarly, in places southwest of this area, where metamorphism has been more intense, rocks of the biotite and biotite-almandite facies transgress this line. The near coincidence of the biotite isograd and the Martic line in the Lynchburg area would appear, therefore, to be fortuitous. It is also probable that the coarser Lynchburg sediments allowed greater mobility of emanations and pore liquids than did the finer-grained Candler sediments, so that adjustment to rising temperatures during metamorphism was more

rapid and complete in the Lynchburg formation, causing it to tend toward higher grade.

MINOR STRUCTURAL FEATURES

General statement.—Minor structural features such as axial-plane and slip cleavage in conjunction with bedding; drag folds; and lineations are well developed in most of the metasediments of the area and are of great value in the determination of larger structures.

Bedding.—Bedding is discernible in all of the metasedimentary formations and is particularly well preserved in the quartzites, marbles, and gneiss (Pl. 3A, 5A, 5B, 6A, 7A, and 7B). It is best observed where weathering has accentuated compositional and color differences in the strata.

Bedding foliation.—Bedding foliation is a schistosity essentially parallel to bedding. It is developed in most schistose and gneissose rocks of the area and particularly those of the Lynchburg formation. It is shown to be a true bedding foliation by the fact that it maintains essential parallelism to bedding around the axes of folds as well as on the limbs. Mead (1940, p. 1009) suggests that such foliation may result from an accentuation of bedding by growth and enlargement of primary platy and elongate constituents under metamorphism without the operation of plastic deformation or shear. In rocks of this area, the abundance of platy minerals paralleling the bedding seems to indicate that considerable neomineralization accompanied the process. In that this foliation is parallel to bedding in all parts of folds, and it is bent or transgressed by all minor structures definitely related to folding, it is thought to have developed prior to and independently of folding.

Axial plane cleavage.—Axial plane cleavage is a cleavage dependent upon mineral parallelism and alignment developed more or less parallel to the axial planes of folds. It is locally developed in all of the metasedimentary formations of the area but is distinguishable from bedding foliation only near the axes of folds where an angular relation with bedding can be seen. Where the larger relations could be checked, it proved to be reliable in the determination of tops and bottoms of beds.

Fracture cleavage.—Fracture cleavage is a shear-plane cleavage which is dependent chiefly upon closely spaced subparallel fractures rather than mineral orientation. It is not widely developed in

this area but is locally present in the quartzites and siliceous phases of the Arch marble (Pl. 7A) and Joshua schist. In the few places where its relations could be well observed, it showed typical flaring fan-fashion from the axial planes of folds and gave every indication that it could be depended upon in tops of beds determinations.

Slip cleavage.—Slip cleavage (also called "false cleavage," "strain-slip cleavage," "ausweichungsclivage," etc.) is a cleavage which has been imposed upon and is transverse to an earlier foliation (Pl. 5C, 7B, and 11A). It is a shear phenomenon and results from the bending of the pre-existing foliation into and the extension of this foliation along planes of shear. Most typically, extension along these planes has been great enough to cause rupture. Bending is in the form of tiny folds which range in shape from simple monoclines (Pl. 11A) to tight crinkles. The shape of microfolds formed is determined partly by compressional crowding of rock material into crests and troughs of folds and within the steeper limbs of asymmetric folds (microdrag-folding). It also appears to be determined partly by the directional relation between the earlier foliation and the shearing movement. Crinkles form most readily where the shearing movement is strongly transverse to or "against the grain" of the earlier foliation, monoclines where the angular relation is 90 degrees or less (Fig. 6). Slip cleavage parting planes are less closely spaced than in most other types of cleavage, having a spacing of less than a millimeter to one inch or more. These parting planes are generally along the extended limbs of the microfolds but may be along the axial planes of tight crinkles.

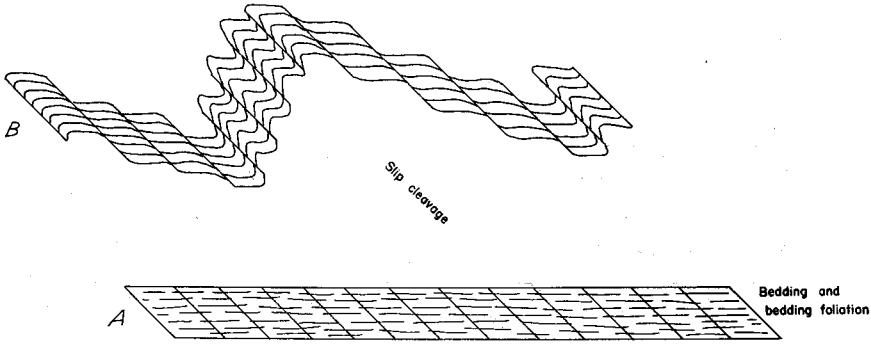


FIGURE 6.—Sketch of slip cleavage imposed upon bedding foliation, showing theoretical development of crinkles on steep limb of asymmetric fold and simple monoclines on flatter limb.

Slip cleavage, being a shear phenomenon, may form under any conditions where shearing forces are applied in a direction transverse to a pre-existing foliation. Where it results from forces involved in folding, it appears to be completely analogous to fracture cleavage. Like fracture cleavage, it tends to be more or less parallel to the axial planes of folds but commonly shows considerable flaring or fanning outward from these planes on the limbs.

In some parts of the Virginia Piedmont, for example, eastern Albemarle County, slip cleavage appears to have been developed on a regional scale upon previously tighely folded rocks. In these areas it is useless in tops of beds determinations. In the Lynchburg quadrangle, however, in all formations with an appreciable proportion of competent beds, it appears to have the same relation to folds as fracture cleavage and is usable in the same way in the delineation of folds. This relation probably cannot be relied upon in relatively massive formations like the Candler.

In this area, slip cleavage is generally imposed upon bedding foliation. It is most widespread and a most useful secondary minor structure in the Lynchburg formation. In all thin sections from this formation showing slip cleavage, strain in the bent micas had been relieved and most ruptures healed by new crystal growth. Slip cleavage in this part of the Lynchburg formation, therefore, is now a mimetic slip cleavage (Sunderman, 1952).

In the Lynchburg formation, slip cleavage is confined to the less competent schistose layers between more competent quartzose beds. Folding in the latter, therefore, appears to have been flexure folding. The fact that slip cleavage in the schistose layers is well developed not only on the limbs but also on the axial portions of folds, however, indicates that in these layers folding was of the shear type (Pl. 5B and 5C).

Minor folds.—Minor folds in or closely associated with relatively competent strata appear generally to be an expression of the same forces which produced larger folds. Axial planes, for the most part, are steeply inclined to the southeast and most axes plunge at low angles to the horizontal. Minor folds in the more massive, relatively less competent phyllites and marbles, however, appear to have no definite relation to large structures. In these, plunge is commonly quite steep, usually to the south but not infrequently to the northeast (Pl. 6A). These folds are later than schistosity, probably developed after bedding was steeply inclined, and probably express reorientations

of stress at places where forward movement was locally impeded by irregularities in fault planes or impingement against less mobile rock masses. The usual dextral pattern of these folds in plan and southward plunge of axes would seem to indicate general east to west compression imposed upon the major southeast to northwest major compression.

Lineations other than fold axes.—Linear structures of numerous types are abundant in rocks of this area and are of value in the interpretation of the local and regional movement pattern. Axes of minor folds have been considered in the discussion of such folds. Other common linear structures are crinkle axes, intersections of cleavages, intersections of cleavage with bedding, rodding or pencilling in brittle rocks, boudinage, and mineral elongations.

Crinkle axes, intersections of axial plane and slip cleavage with bedding and bedding foliation, are generally more or less horizontal. They appear to approach parallelism with the axes of large folds.

Quartzites locally show strong rodding, or deformation into elongate, rounded, pencil-like masses (Pl. 6B). This structure appears to be best developed near the axes of sharp flexures, and particularly at the steeply plunging end of such flexures.

Boudinage, often of large size, is common in parts of the Lynchburg formation, particularly in the somewhat crumpled central parts of close folds (Pl. 3A). It is also found in beds of quartzite enclosed in schists and phyllites of the Candler formation. In most cases, the boudins are nearly horizontal and approach parallelism with fold axes.

Mineral elongations parallel to cleavage and more or less normal to fold axes are most prominantly developed in the greenstones, Reusens migmatite, and the hornblendic rocks. They show stretching or mineral growth in the direction of movement.

GEOLOGIC HISTORY

The oldest rocks exposed in this region are the heterogeneous hornblende and biotite gneisses of the Moneta. Before metamorphism, much of the biotite-quartz gneiss was probably graywacke to arkosic sediment; the original nature of the hornblende gneisses is unknown, but they may be metamorphosed calcareous sediments or basic igneous rocks. The group was possibly part of a pre-Appalachian geosynclinal sequence which, in early Proterozoic time, after deep burial, strong deformation and metamorphism, was affected over wide areas by migmatitic and magmatic processes which produced the Virginia Blue Ridge complex. The orogeny, of which these processes were doubtless a part, was followed by long erosion during which these plutonic rocks were denuded.

In late Precambrian time, clastic sediments, forming an onlap from east to west, were laid upon this erosion surface. These sediments, which now comprise the Lynchburg formation and its probable partial equivalent, the Swift Run formation to the west, appear to mark the earliest effects in this area of the initiation of the Appalachian geosyncline. It is not known whether the Lynchburg formation is dominantly of marine or terrestrial origin, but at least the lower part of the formation, particularly the Rockfish conglomerate, may well be largely terrestrial. A bed of marble, 30 feet thick in the upper part of the Lynchburg formation 2 miles west of Evington and 5 miles southwest of the Lynchburg quadrangle, suggests that true marine conditions prevailed in parts of the area before the end of Lynchburg time. The source of the Lynchburg clastics of the western Piedmont of Virginia seems to have been dominantly from the west, but frequent conglomeratic beds in the upper Lynchburg of the Sherwill anticline in the southeastern part of the Lynchburg quadrangle suggest also at least a local source to the southeast.

In late Precambrian, or early Cambrian time (Bloomer and Bloomer, 1947), spilitic Catoctin volcanics were extruded widely in the Piedmont and Blue Ridge regions; and abundant mafic and plentiful ultramafic bodies were formed as intrusive or metasomatic masses in the Lynchburg formation and underlying plutonic rocks.

The volume of Catoctin volcanics was considerably less in the Lynchburg area than in portions of the Piedmont to the northeast and in the Blue Ridge. In these latter regions, some sediments, mainly graywackes, sandstones, and tuffs, were deposited between flows

(Bloomer, 1950, p. 773). In the Lynchburg area, as Catoctin time was approached, sediments of the Lynchburg formation tended to become finer firained; and, during Catoctin volcanism, sediments generally finer grained than average Lynchburg were plentifully deposited between flows. In places on the southeast flank of the James River synclinorium these interlayered sediments reach thousands of feet in total thickness, showing that here, at least, the basin of sedimentation was being actively deepened and volcanism was almost certainly submarine.

In the Lynchburg area, except for the presence of Catoctin volcanics and a rather rapid change from medium-grained to fine-grained graywacke sediments, no marked break in sedimentation is evident at the top of the Lynchburg formation. Before and during Catoctin volcanism, fine-grained graywackes with some sandstone and impure limestone accumulated to a thickness in excess of 4000 feet. These sediments have been mapped by the writer as the Candler formation.

Following Candler sedimentation, deposition continued without noticeable break, first into the graphitic and somewhat more calcareous sediments of the Joshua formation, then into the Arch marble phase in which impure limestones were dominant, and finally into the graywacke sediments of the Pelier formation. Graywacke deposition was followed by some local erosion and a change to deposition of quartz conglomerates, sandstone, shales, and rather pure limestone lenses of the Mount Athos formation. The clastics of the Mount Athos formation thicken and coarsen to the west, showing the prevailing source to have been in this direction.

The coarse sediments of the Mount Athos formation apparently marked appreciable changes in shorelines and nearby lands which were climaxed by a new period of volcanism, during which the Slippery Creek andesitic and basaltic flows were poured out rather widely in this region. No younger rocks, except Quaternary alluvium, are found upon these flows in this area.

During or near the close of Paleozoic time, all presently existing pre-Triassic rocks in the area underwent low to middle grade metamorphism (muscovite-chlorite to staurolite-kyanite subfacies) and were strongly deformed by forces directed toward the northwest. Flowage and degree of metamorphism indicate that existing rocks were under an appreciable cover of younger Paleozoic rocks at the time of deformation, but erosion has removed other record of these.

Deformation and metamorphism of the Paleozoic rocks of the

Piedmont have generally been assigned to the late Paleozoic Appalachian revolution, but the concept that the rocks of the Piedmont lay in the inner zone of the more or less continually mobile Appalachian geosyncline suggests that they developed progressively through Paleozoic time (King, 1951, p. 134). This theory of earlier periods of deformation and metamorphism in the Appalachians is upheld by age determinations on granites of about 350 and 260 million years (Rodgers, 1952).

In upper Triassic time, extensive normal faulting occurred in parts of the Piedmont producing elongate basins in which continental sediments accumulated. This was accompanied and probably followed in part by intrusions and flows of diabasic material. That the Lynchburg area was little affected by these events is shown by the absence of Triassic sediments and definite normal faults, and by the presence of only two small diabase dikes.

From Triassic time to the present, the history of the Piedmont is largely one of erosion and periodic uplift. Extensive peneplanation appears to have occurred at least twice and perhaps three times, depending upon whether the Fall Zone surface is older than the Schooley (Fenneman, 1938, pp. 158-160) or was a continuation of the Schooley as suggested by Stose (1940). The present upland Piedmont surface was probably formed by late Tertiary time, and moderate elevation since then caused streams to deepen their valleys and to begin the dissection of the Piedmont surface.

MINERAL RESOURCES

GENERAL STATEMENT

The chief mineral resources in the Lynchburg quadrangle are: marble (limestone), "Virginia Greenstone," sand, granitic rock, manganese, barite, and iron ore. Iron, "Virginia Greenstone," and probably marble were used as early as the latter part of the Eighteenth Century. No iron has been mined since about 1882, but the other two are in important production at present. Manganese has been produced intermittantly since the eighties from two of the largest manganese mines in the region and numerous small mines. Granitic stone has been taken from several small quarries; and, for a number of years, sand has been dredged from James River by one operator.

MARBLE

General statement.—The potential economic value of marble and limestone in the Lynchburg area was recognized as early as 1839 by William Barton Rogers (1884, pp. 81, 298), first State Geologist of Virginia, who described numerous localities and suggested that the stone be used for agricultural, "architectural and household" purposes. Somewhat later, a number of small kilns were built in the area for the preparation of agricultural and household lime; and Campbell (1882, p. 83) states that the stone was used in the masonry about the locks in the James River canal, and that considerable quantities from near Mount Athos were used as flux in the Lynchburg iron furnace. The stone also has had local use as hewn blocks in chimneys and in house and bridge foundations. At present, two large quarries are in operation and the stone is crushed for use as road metal and concrete aggregate.

Marble of the Lynchburg area is of two types and occurs chiefly in two different stratigraphic positions. The first, blue-gray, banded, and more or less schistose, comprises the principle part of the Arch formation and also occurs in minor amount within the Candler formation. Although commonly called "limestone", it has the fine- to medium-grained crystallinity of a marble. The second, a white to gray or pink, medium- to coarse-crystalline, fairly pure carbonate to highly siliceous marble with schistose bands, forms local, non-persistent lenses within the quartzites and schists of the Mount Athos formation. Arch marble is much more extensive but generally less pure than marble of the Mount Athos formation. Present quarrying operations

and most, if not all, such operations of the past have been in Arch marble. Although not utilized in the Lynchburg quadrangle, Mount Athos marble is quarried on a considerable scale in Appomattox and Pittsylvania counties and used as ground agricultural limestone. Some of the large bodies in the Lynchburg area could almost certainly be similarly utilized.

Both Arch and Mount Athos marble, being less resistant than enclosing rocks, tend to form valleys, and outcrops are rare except in or near streams. Where marble extends through higher areas between streams its carbonate generally has been leached to a considerable depth and, near the surface, only an insoluble residuum remains. This residuum is recognizable, however, and indicates the presence of marble beneath. Mount Athos marble generally weathers to a "punky," black, micaceous, sandy earth; Arch marble typically goes to a banded, highly variegated blue-gray, white, yellow to red clay containing porous, calcicastic masses of vein quartz.

Both Arch and Mount Athos marble have been described in detail in the formational descriptions and their surface extent shown in Plates 1 and 14; the location of quarries also is shown in Plate 14.

Arch marble.—Blue-gray, banded, schistose marble of the Arch formation crops out chiefly along the northwest flank of the James River synclinorium, in a belt extending from the southwest corner of the quadrangle northeastward to where James River leaves the quadrangle. Here and there within this belt, the marble has been repeated by folding, and repeated or cut out by thrust faulting. Thrusts have also raised marble to view in places within the central part of the synclinorium; the occurrence of Arch marble along the southeast flank of the synclinorium is sporadic.

In 1956, the Blue Ridge Stone Corporation opened a quarry in Arch marble of a thrust block of the main northwestern belt (Pl. 14, loc. 79). This quarry, near the Norfolk and Western Railway 1½ miles southeast of Jack Mountain and 4½ miles southeast of Lynchburg, is 500 feet long, 200 feet wide, and 50 feet deep; the crushing plant produces about 200 tons per hour. The stone is used for road metal and concrete aggregate. The same year, Rockydale Stone Service Company opened a quarry just north of Archer Creek, near "the Arch" on the Norfolk and Western Railway 1¼ miles east of Six Mile and 5 miles east of Lynchburg (Pl. 14, loc. 34). This quarry is 600 feet long, 300 feet wide, and 55 feet deep; the crushing plant produces 250 tons per hour (E. O. Gooch, personal communication). The

Rockydale quarry is in Arch marble of the easternmost of two subparallel thrust blocks within the central part of the synclinorium. This well-known locality was visited by Rogers (1884, p. 304) and analyses of stone from the vicinity were published by Britton (1881). Britton's analyses are repeated below in Table 8. At one time this stone was burned for lime, and the remains of an old kiln near "the Arch" and another at a place 0.6 mile to the east still stand.

TABLE 8.—*Analyses of marble in vicinity of "the Arch" on the Norfolk and Western Railway 5 miles east of Lynchburg. (J. B. Britton, analyst)*

	1	2	3	4	5
Lime carbonate	77.67	67.85	82.45	65.10	91.51
Magnesia carbonate	3.78	6.02	2.10	2.96	2.59
Silica	15.88	20.42	10.98	26.90	.....
Alumina	.97	1.20	.70	.86	.....
Water	.27	.41	.16	.21	.41
Iron protocarbonate	1.16	3.80	2.90	3.94	.....
Iron peroxide	.....				
Iron pyrites	.....	.22	.19	.....	.....
Phosphoric acid	.003	.006	trace	.004	.....
Manganese oxide	.07	trace	trace	trace	.....
Iron and manganese oxides and alumina	.....	.....	.....	.....	2.77
Insoluble siliceous matter	.....	.....	.....	.....	2.56
Undetermined and loss	.197	.074	.52	.026	.16
	100.00	100.00	100.00	100.00	100.00

1. Blue limestone from a nearly vertical stratum about 3 feet wide, on the north side of the Norfolk and Western Railway.
2. Light-blue limestone from seam about 25 feet wide, about 300 feet north of "the Arch."
3. Same as above, but of a dark-blue color.
4. Blue limestone from a stratum about 50 feet wide, exposed in a branch a little south of the railroad.
5. From a stone crystalline in structure, and locally known as white limestone; taken from a stratum, about 40 feet of which is exposed in the bed of a branch.

Other excellent exposures of Arch marble occur in vicinity of Six Mile on the Norfolk and Western Railway 4 miles east of Lynchburg and in and near Flat Creek in the southwestern part of the quadrangle. Half a mile north of Six Mile a 50-foot bed of good quality, gray-banded stone is exposed in a low ridge between the county road and the Chespeake and Ohio Railway. Rock from this locality has been burned for lime, and remains of the old kiln stand nearby. This is probably the locality referred to by Rogers (1884, p. 391) as "James River below Archer's Creek" from which he

took a sample that analyzed 79.5 per cent carbonate of lime. This belt of stone is continuous northeastward beyond where James River leaves the quadrangle, but exposures occur only in small northwestward-flowing tributaries to the James. A mile southwest of Six Mile, near the mouth of Opossum Creek, very siliceous Arch marble has been quarried on a small scale for use as road metal and rough building stone (Pl. 14, loc. 45). Less siliceous stone is exposed in numerous places in Opossum Creek to the southwest and here and there along Little Opossum Creek to the west.

Contorted Arch marble is exposed in numerous places in and near Flat Creek, at a place about a mile northeast of where it is crossed by U. S. Highway 29 southwestward beyond Lawyer. Marble, apparently belonging to a thrust block from the southeast, is also well exposed beside U.S. Highway 29 half mile southeast of its crossing of Flat Creek. The rock exposed in Flat Creek is not well situated for quarrying but appears better situated southwest of Lawyer where the main mass of marble lies northwest of Flat Creek. An excellent exposure is in an easterly flowing tributary to Flat Creek on the A. A. Garbee property 0.8 mile southwest of Lawyer. Stone from this vicinity was burned for lime many years ago, and it is said that plaster made from this lime is still good after 70 years. An analysis of stone from this locality is give in Table 9 (No. 1).

Mount Athos marble.—Outcrops of the white, gray, and pink, medium- to coarsely-crystalline marble of the Mount Athos formation in this quadrangle are largely restricted to the southeasternmost outcrop belt of this formation. This belt enters the quadrangle 3 miles northeast of Oxford Furnace, extends southwestward across Archer and Little Beaver creeks, along Beaver Creek and Smith Branch, in part, and leaves the quadrangle near its southwest corner (Pls. 1 and 14). In places within this belt, gray Arch marble is associated with that of the Mount Athos formation; but through much of this belt, the Arch marble is missing either because of faulting or nondeposition. One small exposure of white, fine-grained Mount Athos marble not in the southeastern belt is in a tributary of Joshua Creek, 3 miles northeast of Oxford Furnace, in the easternmost of the three thrust slices within the central part of the James River synclinorium in this vicinity.

On the south side of Archer Creek, 0.7 mile northeast of Oxford Furnace, a 20-foot thickness of cream-white Mount Athos marble crops out in a projecting bluff below a house. This marble is bordered on the northwest by 40 feet of greenish mica schist of possible tuffa-

ceous origin and on the southeast by about 15 feet of very porous quartzite with a show of manganese. Two hundred yards further to the southeast, gray, highly contorted Arch marble is well exposed in and beside Archer Creek for a distance of 200 feet. Between Archer Creek and Little Beaver Creek to the southwest, marble is not seen at the surface, but a 70- to 90-foot thickness of white marble was encountered in mining and exploratory drilling at the Piedmont manganese mine 700 feet northeast of Little Beaver Creek (Espenshade, 1954, p. 110). At Little Beaver Creek, white chlorite marble interbedded with porous quartzite lies southeast of gray-banded marble.

The best and most continuous exposures of marble in this southeastern belt are southwest of the Norfolk and Western belt line railroad, in and near Beaver Creek and its tributaries. A quarter of a mile southwest of the railroad at a place 0.8 mile southeast of its crossing of Beaver Creek, a 200-foot thickness of cream-colored marble is well exposed in a slope just west of a private road. Conditions appear rather favorable for quarrying, and stone from one small opening (Pl. 14, loc. 66) has been burned for lime. A slab of the stone was found to take a nice polish, and chip samples yielded the analysis in Table 9 (No. 2).

Immediately southwest of the above exposure, gray Arch marble is exposed in numerous places in and near Beaver Creek and, at one place, there is another small abandoned quarry (Pl. 14, loc. 67). Still farther southwestward, to and for a mile beyond U.S. Highway 501,

TABLE 9.—*Analyses of limestone and marble in the Lynchburg quadrangle (J. H. Yoe, analyst)*

	1	2	3
SiO_2	19.82	2.62	4.63
R_2O_3	2.18	3.25	2.10
$CaCO_3$	66.30	79.0	83.10
$MgCO_3$	15.90	15.9	12.70
Total	104.20	100.77	102.53

1. Arch marble on A. A. Garbee property 0.8 mile southwest of Lawyer. Chip samples taken over a distance of 1200 feet across the strike.
2. White Mount Athos marble on W. T. Lindsay property 0.8 mile southeast of the Norfolk and Western Railway crossing of Beaver Creek, 5 miles southeast of Lynchburg (Pl. 14 loc. 66,). Chip samples taken across 200-foot thickness.
3. White Mount Athos marble on G. C. McGehee property near Smith Branch, 1.7 miles southeast of Lawyer. Chip samples taken across 300-foot thickness.

gray, white, and pink, medium- to coarsely-crystalline marble corps out along the west side of Beaver Creek and nearby in most of its eastward-flowing tributaries. The amount of quarryable stone in this belt appears to be large.

One other body of Mount Athos marble belonging to this southeastern belt is on the G. C. McGehee property in vicinity of Smith Branch, 1.7 miles southeast of Lawyer (Pl. 14, loc. 89). A 15-foot width of white and pink marble is exposed at the base of a bluff on the south side of this stream; in strike to the southwest, a 300-foot thickness of cream to white stone is exposed in the first small northwestward-flowing tributary. The stone contains some biotite and scattered crystals of sulfide. Quarrying conditions appear rather favorable, except that overburden may be thick away from stream valleys. An analysis is given in Table 9 (No. 3).

"VIRGINIA GREENSTONE"

At Daniel Avenue and Harper Street, Lynchburg, the Virginia Greenstone Company, Incorporated, quarries a dark rich green variety of actinolite-chlorite schist and an associated gray tremolite-chlorite schist. Both are sold under the trade name "Virginia Greenstone." The actinolite variety is further designated "regular green stock;" the tremolite variety is referred to as "gray stock." About a third of the stone is used as broken and dimensioned flagging, but about 90 percent of the value of stone produced is finished and shaped for architectural purposes. The regular green stock is quite resistant to weathering and is well suited for its many exterior as well as interior applications. These include spandrels, sills, coping, store fronts, entrance floors, stair treads, risers, floor tiles, trim, wainscoting, base, fireplace facings, and hearths. Use of the gray stock, which is somewhat harder than the green, is restricted to interior applications because of the presence of ankerite which tends to stain brown under action of the weather.

It is not known exactly when "Virginia Greenstone" was first quarried, but the Quaker Meeting House completed in 1798 was built of this stone. Among other early buildings in Lynchburg that were built of greenstone was the Epiphany Chapel on the edge of Miller Park which was completed in 1865. During the 1920's C. G. Loving purchased the old quarry and erected a small finishing plant on Fort Avenue. In 1931 the present corporation took over the property and its operations have been continuous since that time.

"Virginia Greenstone" belongs to the ultrabasic association of rocks which include peridotite, serpentinite, and soapstone. The origin of and relations within this association have been discussed elsewhere.

At the greenstone quarry, the green and gray varieties both occur in the same body, the gray generally dipping northwestward beneath the green opposite to the slight general foliation which dips steeply southeastward. The boundary varies from sharp to gradational over a distance of a few feet. The body has a maximum thickness of about 300 feet and has been traced for four miles. Excellent stone extends for some distance beneath residential areas immediately to the southwest; but southwest of Lynchburg the body divides into several branches and its character changes; locally it becomes more schistose and paler in color. While the mineral assemblage is the same, the proportions are different.

Several other similar bodies occur in the area but have not been proved commercial (Pl. 1.) The largest of these are 1½ miles northwest of Round Mountain in the northeast corner of the quadrangle, and just west of U.S. Highway 29 a mile southwest of the city limits of Lynchburg. Soapstone and serpentinite, although lacking in the body quarried by the Virginia Greenstone Company, are prominent at the first locality and peridotite and hornblende gneiss occur at the second. Most of these similar bodies are pale rather than dark green, too hard or too schistose, lack sufficient size or uniformity, or contain too much ankerite which weathers out leaving holes and iron stains.

Petrographically, "Virginia Greenstone" is a dark green, coarse-grained, more or less "knotted" actinolite-chlorite schist. In thin sections, the porphyroblasts are seen to be ragged crystals of actinolite as much as 1 cm. long, enclosed in a matrix of fine chlorite interspersed with tiny grains and needles of actinolite. The porphyroblasts are partly chloritized and their ends have a shredded appearance. The rock is cut by numerous micro-shear breaks which cut or bend around porphyroblasts and are filled with coarser chlorite including fragments of actinolite. Both chlorite and actinolite are pale green and weakly pleochroic. Irregular grains of magnetite are dusted through the rock.

Tremolite-chlorite schist, Virginia Greenstone Company's "gray stock," is light gray to greenish gray when unpolished, medium to dark gray when polished, medium- to coarse-grained, more or less porphyroblastic, and weakly to distinctly foliated. The chlorite is less green than that in the "green stock," and tremolite takes the place of actinolite in the less prominent porphyroblasts and is more abundant in the

matrix. Ankerite is scattered through the rock and locally forms veinlets; opaque minerals include pyrite, pyrrhotite, and magnetite.

SAND

For a number of years, J. M. Smiley has dredged sand from James River for use chiefly in concrete block, mortar, and plaster. Formerly his operations were above the dam at Lynchburg but, at present, he has two dredges above the Reusens dam. The sand is pumped from the bottom and passed through a quarter-inch screen into the dredge, then unloaded by dragline.

GRANITIC ROCKS AND HORNBLENDE GNEISS

In the northwestern part of the Lynchburg quadrangle, northwest from the vicinity of Peakland, are found: 1) mixed granitic and hornblende gneisses, 2) prevailingly granitic gneisses, and 3) nearly massive granite rock (Pl. 14). The first has been quarried just south of Monroe (Pl. 14, loc. 3) and at Peakland (Pl. 14, loc. 4); the second a mile west of Winesap (Pl. 14, loc. 2); and the third at Abert near where James River enters the quadrangle (Pl. 14, loc. 1). Stone from these quarries has been used as road metal and railroad ballast and in walls, foundations, and bridge abutments.

MANGANESE ORE

GENERAL FEATURES

Manganese deposits in a district extending from Roanoke River to Albemarle County, and including all known deposits in the Lynchburg quadrangle, have recently been described with great thoroughness by Espenshade (1954). For this reason, only certain of the more important features of deposits in this quadrangle will be considered here.

Espenshade (1954, pp. 52-54) recognized two generalized types of ore, "psilomelane type" and "wad," each of which may include one or several distinct minerals. The first is bluish black, hard, and heavy; its texture is dense to finely crystalline; in form it is nodular or botryoidal to slabby. "Wad" includes massive, soft, brown to black material of apparent low specific gravity and rather high moisture content; it consists of mixtures of manganese oxides and clay, sand, or mica. In the past, only the hard nodular or lumpy psilomelane-type has been commercial; wad could become commercial if uses are found for material of low manganese content or if suitable methods of beneficiation are developed.

All deposits are associated with the Mount Athos formation, usually with some of its more calcareous portions. Espenshade (1954, pp. 62-63) found manganese present in nearly all of numerous specimens of Mount Athos marble and calcareous quartzite tested and, with little question, these rocks were the source of the manganese. The ores were apparently concentrated by meteoric waters percolating downward chiefly through porous quartzite members of the Mount Athos formation. The depth to which deposits extend, therefore, is limited to the depth to which ground waters circulate, probably not over 300 to 400 feet. Concentration is thought to have taken place beneath an old erosion surface, probably in Tertiary time (Hewitt, 1916, pp. 43-47; Espenshade, 1954, pp. 59-72). This relation to a former flattish surface is suggested by statistics which show that a majority of the deposits (65.4 percent) and most of the manganese production from the district (82 percent) has come from mines that outcrop at elevations from 600 to 800 feet above sea level (Espenshade, 1954, p. 68).

The four principal modes of occurrence of ores recognized by Espenshade (1954, pp. 55-58) and his more pertinent comments concerning each are summarized below:

1) *Nodules and masses of psilomelane-type oxides in seams of clay, chert, or decomposed rocks, conformable to the dip of bedding or cleavage which is usually steep.* These appear to develop in association with calcareous quartzite, which, upon weathering, permits easy circulation of manganese-bearing ground waters. The deepest and the most productive deposits in the district have been of this type. In most deposits, the proportion of manganese oxides to clay is small, although it is said that parts of the ore bodies in the Piedmont and Saunders mines were practically massive manganese oxides with only minor clay.

2) *Psilomelane-type oxides forming coatings or fillings in cavities in fractured rock, as in open fractures and as the matrix in a breccia of quartz and quartzite fragments.* These are generally small and of no commercial importance.

3) *Wad mixed with clay and seams interlayered with clay or decomposed rock conformable to the bedding or cleavage.* These appear to develop chiefly from the decomposition of nearly pure marble and probably do not extend to depths much below drainage. Friable, granular manganese oxides occur as stringers or seams in many wad

deposits; but the nodular oxides, so common in yellow clay seams, are very scarce in wad.

4) *Residual concentrations of psilomelane-type minerals in the red clay soil overlying eroded manganese deposits.* These are usually relatively thin, often only 1 to 2 feet thick, so the amount of ore accumulated in this manner may be negligible compared to the size of the underlying ore body. Some unusually rich accumulations, however, have been found.

MINES AND PROSPECTS

The fact that a show of manganese can be found in almost every outcrop of Mount Athos formation has led to shallow pit prospecting throughout much of the extent of this formation in the area. In addition, two of the largest mines in the James River-Roanoke River manganese district, the Piedmont and the Leets, and a number of small mines have been opened in the Lynchburg quadrangle (Pl. 14).

Most deposits in the area which have been worked apparently were discovered and opened during the period 1880 to 1919. Peak recorded production was during the years 1911 to 1919 when operations at the Piedmont mine were most active. There was little or no production from 1919 until 1933 when the Leets mine was reopened and operated for two years. The district saw very considerable renewed activity between 1937 and 1945 but production never approached that of former peak periods. Espenshade (1954, pp. 82-83), referring to the whole James River-Roanoke River district, states: "Production, however, during the period 1937-1945 amounted to only 993 tons from about 20 deposits, compared to the 1930-35 production of 1,035 tons, or the 1911-1918 production of 7,607 tons. . . . the total amount produced is not accurately known. The official recorded production is 26,107 long tons, but it is probable that the total quantity of washed ore produced is twice as large as this figure."

In recent years, most locally produced ores have been sold to the National Paint and Manganese Co. of Lynchburg, which years ago operated certain of the mines in the district, and to E. J. Lavino Co. at Reusens, manufacturers of ferromanganese.

Piedmont mine.—This mine, also called Lerner or Myers mine, is on a small knob between Little Beaver Creek and U.S. Highway 460, half a mile southeast of Oxford Furnace and 5½ miles southeast of Lynchburg (Pl. 14, loc. 57). It has been by far the most productive

mine in the James River-Roanoke River manganese district, with an estimated total production of 30,000 tons of ore. The history of operation and the geology of the deposit have been described in detail by Harder (1910, pp. 38-40), Hewitt (1916, pp. 49-54), and Espenshade (1954, pp. 109-114). The following notes have been taken chiefly from these writers.

First mining in the vicinity was for iron and it is possible that manganese was found during the search for iron. Manganese mining was begun in the early eighteen-nineties by the Lerner Mining Company. Between 1902 and 1912 the Piedmont Manganese Company sank and recovered ore from the Josephine shaft to a depth of 105 feet. The most intensive mining was by the Piedmont Manganese Corporation between 1912 and 1914, when a narrow-gauge tramway was built from the mill to the Chesapeake & Ohio Railway, mining was carried on from the Josephine shaft to a depth of 150 feet, and the new Oxford shaft was sunk to a depth of 190 feet. In 1915, the Oxford Mining and Manganese Company deepened the Oxford shaft to 208 feet and recovered ore from that level. Operations were abandoned in 1918, but it is reported that, before this time, mining was carried 10 to 15 feet below the 208-foot level and a winze was sunk 25 feet below this mined portion and was still in ore (Espenshade, 1954, p. 109). Next production was not until shortly after World War II when the Myers Chemical Company started mining wad for the manufacture of manganese sulfate for use in fertilizer. In 1955, the D.B.D. Mining Corporation of Lynchburg shipped about 70 tons of ore from the mine but this probably was recovered chiefly from the dumps (E. O. Gooch, personal communication).

Hewitt (1916, p. 52) states that there were two considerable masses of ore separated by an area of unaltered mica schist. Espenshade's (1954, p. 110) summary description of the southwestern and larger body, which was mined through the Josephine and Oxford shafts, is as follows:

"The main ore body is an elongate lens with its longest dimension (more than 200 feet) down the dip, and a strike length of about 125 feet. Maximum thickness of the lens is 25 to 30 feet. The deposit strikes about N.20° E. and dips from 70° NW. to nearly vertically beneath the quartzite hanging wall. Marble forms the footwall of the ore body and extends from the Oxford shaft to the ore body on the 208 level. The deposit appears to have changed very little, either in shape or in ore content, from the surface to the bottom of mining."

Harder (1910, p. 39), who visited the mine in 1909 when it was being operated on the 80-foot level of the Josephine shaft states:

"The ore occurs in kidneys or large masses and is mainly in the form of granular pyrolusite . . . The ore locally may compose 85 or 90 percent of the ore-bearing clay, forming a nearly solid body with interstices filled with clay, while elsewhere more than half the layer may be clay in which the ore is embedded in lumps. The micaceous clay footwall is light brown, dark brown, or gray, by layers, and is residual from mica schist. The layers and schistosity have the same strike and dip as the ore-bearing layer. The foot-wall clay is similar to the clay associated with the ore and grades imperceptibly into it."

In 1942-43 the Bureau of Mines explored the property by diamond drilling, trenching, and test-pitting. Espenshade (1954, pp. 110-113 and Pl. 8) describes the results in detail and states that, although drilling failed to provide information about the size and grade of ore below the 208-foot level, it showed that the deposit probably pinches out somewhere between a depth of 45 and 170 feet below this level; also that the quartzite and marble wall rocks are quite fresh and unaffected by ground waters at the greater depth.

Leets mine.—This mine, also called Whitman, Mount Athos, and Smithson, is on the north slope of an elongate hill on the south side of Archer Creek 1000 feet south of "the Arch" on the Norfolk and Western Railway, 5 miles east of Lynchburg (Pl. 14, loc. 35). It is the deepest mine in the district and has been one of the most productive. Between 1880 and 1888 at least 1216 tons of ore was mined and most or all of it shipped to England for the making of chemicals (Weeks, 1885, 1886, 1888). Weeks (1893, p. 204) also states that in 1892, "A small amount of very high grade pyrolusite for use in glass-making and the manufacture of bromine has been shipped from a mine near Mount Athos, on the Norfolk and Western Railroad"; but mining apparently ceased about this time, not to be resumed until 1933 when Mr. Smithson of the Southern Mines and Metals Co., Inc. reopened the mine (Espenshade, 1954, pp. 104-105). During this new operation, which lasted until a destructive fire terminated operations in 1935, a shaft was sunk to a depth of 312 feet and at least 975 tons of ore were produced.

Underground workings have been inaccessible since abandonment in 1935, but Watson (1907, p. 240) describes the ore as of nodular or kidney type, occurring chiefly in the form of nests or pockets in residual clay derived from a dark-colored micaceous schist. D. F. Hewitt

of the U. S. Geological Survey visited the mine when it was being worked by Smithson, and Espenshade (1954, p. 105) observed from his field notes that on the 300-foot level there are 4 ore zones. The main zone, lying farthest to the southeast, is 15 to 20 feet thick. No marble was found in the mine.

Drinkard (Herbert) mine.—This small mine is about 1½ miles southwest of the Leets mine and on the same quartzite belt (Pl. 14, loc. 48). In 1941, when the mine was being worked by Robert Adams, a shaft had been sunk to a depth of 70 feet and, at the bottom, a drift and several crosscuts made. Three beds of porous, sheared, brecciated quartzite, separated by mica schist, showed in the crosscuts; each contained appreciable wad but little hard ore. Some good nodular ore was recovered from residual clay near the surface.

Neighbours mine.—This mine is on a quartzite ridge just south of the Blue Ridge Stone Corporation marble quarry on the west side of the Norfolk and Western Railway 3½ miles north of Rustburg (Pl. 14, loc. 80). Espenshade (1954, p. 115) states: "Some mining was done here in 1938 by L. R. Neighbours, owner of the property, and during 1940 and 1941 by the Otter River Mining Co.; about 60 tons of ore is said to have been shipped. The ore was mined from a shaft about 50 feet deep and from several tunnels near the crest of the ridge. Slabby nodules of manganese oxides occur in a seam of yellow clay that is enclosed in quartzite and dops 70° to the southeast." In 1955 mining was renewed by the Harlow Mining Co. of Rustburg, which is reported to have shipped 32 tons of ore.

Bell mine.—This deposit is on the north brow of a quartzite knob 0.4 mile west of U.S. Highway 29, two miles south of City Farm (Pl. 14, loc. 85). R. K. Bell, owner of the property, began mining in 1939 and by October, 1941 had sold 114 tons of washed ore (Espenshade, 1954, p. 117). During this mining, several rather large masses of ore were found. Operations consisted of a 54-foot shaft, two 17-foot shafts, and a shallow open-cut. In 1942, the Bureau of Mines made several exploratory trenches with a bulldozer.

The rocks in the quartzite ridge on which the Bell mine is located are part of a closely folded thrust mass; the mine appears to be in the trough of a tight syncline with steep southeastward plunge. Espenshade (1954, p. 118) suggests that this structure, which may have tended to channelize manganese-bearing waters, plus an altitude well

above that usual for the district, a factor promoting deep circulation, made the location unusually favorable for ore concentration.

Maddox mine.—This property, half a mile west of the Bell mine (Pl. 14, loc. 87), was worked in 1939 by Robert Adams and about 10 tons of ore was shipped (Espenshade, 1954, p. 118). The mine, consisting of a 30-foot shaft and several shallow trenches, appears to be situated on the east flank of a small, tight, southeasterly plunging syncline.

Mortimer mine.—The main shaft of the Mortimer mine, 165 feet deep, is within a fork in the county road 0.7 mile southwest of the juncture of Yellow Branch and Flat Creek, 3 miles southwest of Lawyer (Pl. 14, loc. 100). Mining is said to have begun at this place before 1907, but the main activity was in 1918, when this and the Pribble mine, half a mile to the southwest, were operated by the Virginia Ores Corp. (Espenshade, 1954, pp. 119-120). The two mines together are said to have shipped 525 tons of ore. Several openings were also made northeast of the main shaft and to the west and northwest near the road. During 1942 to 1943 the Bureau of Mines, under the direction of Mr. Bruce Montgomery (1949), explored the vicinity by shafts, crosscuts, and trenches. Much wad and porous manganiferous quartzite and some nodular ore in clay were found.

BARITE

A small amount of barite was recovered some years ago from openings just northwest of Beaver Creek, on the Neighbours (Pl. 14, loc. 71), Carson (Pl. 14, locs. 69 and 70), and Lindsay (Pl. 14, loc. 68) properties 3 to 4 miles north of Rustburg. Concerning the Carson mine, Edmundson (1938, p. 30) states: "The original development is reported to have consisted of a tunnel 100 feet long striking N. 45° E., terminated at the southwestern end by a shaft approximately 100 feet deep." The tunnel and shaft are caved, but there was some new prospecting on the Carson property in 1937. Some fine- to coarse-crystalline, bluish white barite occurs in the dumps.

The occurrence and origin of barite in this region have been thoroughly discussed by Watson (1907, pp. 309-318), Edmundson (1938, pp. 16-24 and 28-30), and Espenshade (1954, pp. 75-78, 142-143, and 148). Everywhere barite occurs it is associated with the white marble of the Mount Athos formation. It occurs as veins and stringers within

the marble and as nodules and masses in the black, manganiferous residual clay derived from the marble.

IRON ORE

During the period of somewhat over a hundred years immediately prior to 1882 iron ore was mined in numerous places within essentially the same portion of the James River synclinorium which has yielded manganese ore. Little can be learned at present from old workings because of their caved and overgrown condition; but Furcron (1935, pp. 81-104), aided by data from old reports by Campbell (1882), Frazer (1883), and others, has well described the main deposits and the occurrence of the ore. Espenshade (1954, pp. 72-75), in a recent statement of new observations and conclusions, along with a summary of Furcron's descriptions, states:

"The iron deposits in the district are of two distinct types: the limonite or brown ore deposits, and the specular hematite deposits. These two types of deposits are very different in their mineralogical and geological characteristics and in their modes of origin. . . .

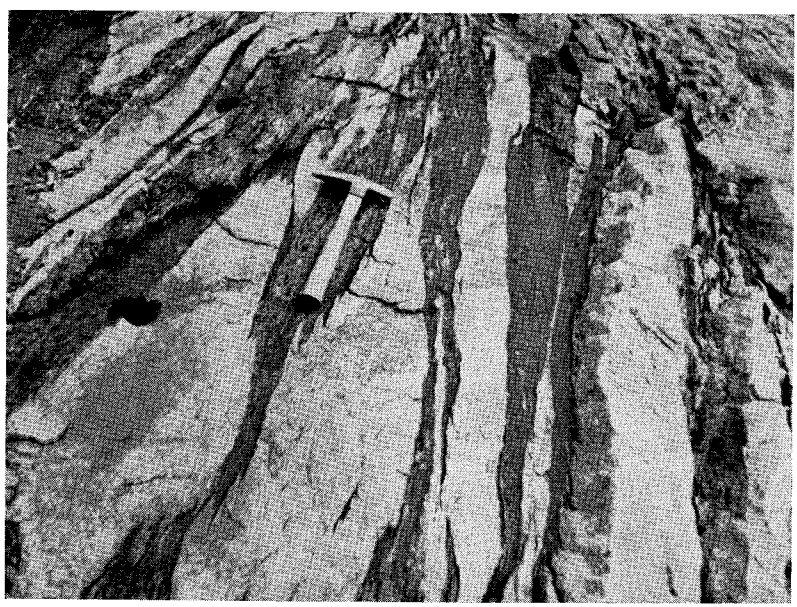
"These limonitic accumulations range in size from a few tons to deposits that probably contain several thousand tons of recoverable limonite, and they have been found to occur with nearly every formation in the region, except the Triassic sedimentary rocks and diabase. They occur most abundantly, however, in mica schists, graphitic mica schists, in quartzite, or along the contacts between quartzite and schist. Some of the larger limonite deposits are in the graphitic mica schist member of the Archer Creek formation [Joshua schist], such as deposits of the old Oxford or Ross mine and those along and near Stonewall Creek. It is assumed that the pyrite disseminated through the graphitic mica schists provided a nearby source of iron for the ground water solutions that formed the limonitic deposits. . . . The limonite deposits are believed to have been formed under similar geologic conditions, and during the same general period, as the manganese deposits of the region. . . .

"The specular hematite deposits consist of iron-rich lenses or seams in schistose and quartzitic beds of the Mount Athos formation. . . . Specular hematite is the dominant iron mineral and is accompanied by minor amounts of magnetite and martite. According to Furcron (1935, p. 84), the lenses that were mined probably averaged only 1 to 3 feet thick, including the lean layers. . . .

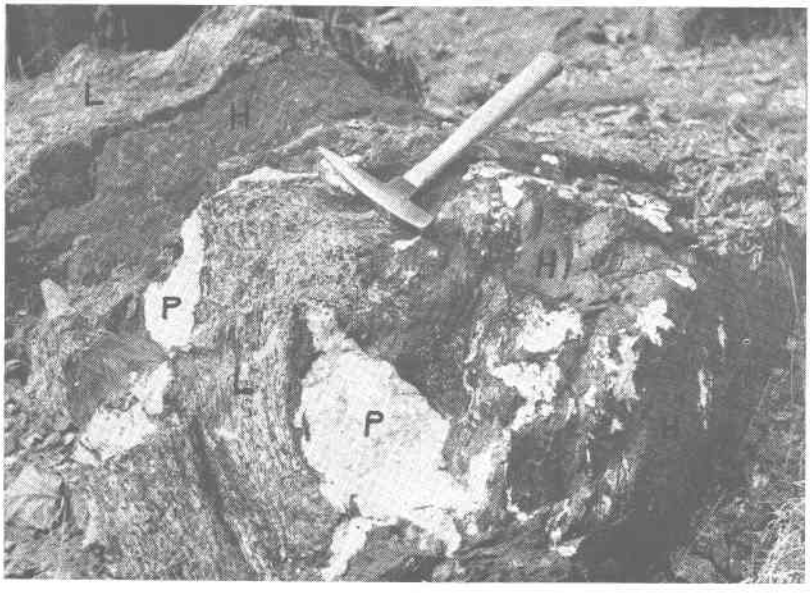
"Several of the early geologists considered these specular hematite ores to be of sedimentary origin; Frazer (1883, pp. 210-211) and Furcron (1935, pp. 98-100) concluded that they probably were hydrothermal in origin. The constant occurrence of the deposits in the restricted stratigraphic interval of the Mount Athos formation, whose calcareous beds contain manganese minerals of sedimentary origin, leads the writer to believe that originally they were formed as thin accumulations of iron-rich sediments, and later they were altered to their present state by metamorphic processes."

The limonitic ores were the first to be mined in the district. Espenshade (1954, p. 82) notes that Jefferson in 1781 indicated that 1600 tons of pig iron was being produced annually from local limonitic ores at the Ross or Oxford Furnace 5 miles east of Lynchburg. This and most other furnaces in the district were out of blast before 1879, when "there was a great boom in the iron industry of this part of James Valley because of the development of hematite and magnetic ores" (Furcron, 1935, p. 82). During this new period of activity, which lasted only until about 1882, some ore was smelted in Lynchburg but most of it was shipped to Pittsburg and other northern furnaces.

2A. Reusens migmatite in quarry at south edge of Peakland. H, earlier hornblende gneiss phase; L, later leucogneiss phase; P, basic pegmatite.



2B. Reusens migmatite on east bank of James River below Reusens dam. Dark bands are diopside-hornblende gneiss; light-colored masses are later leucogneiss.



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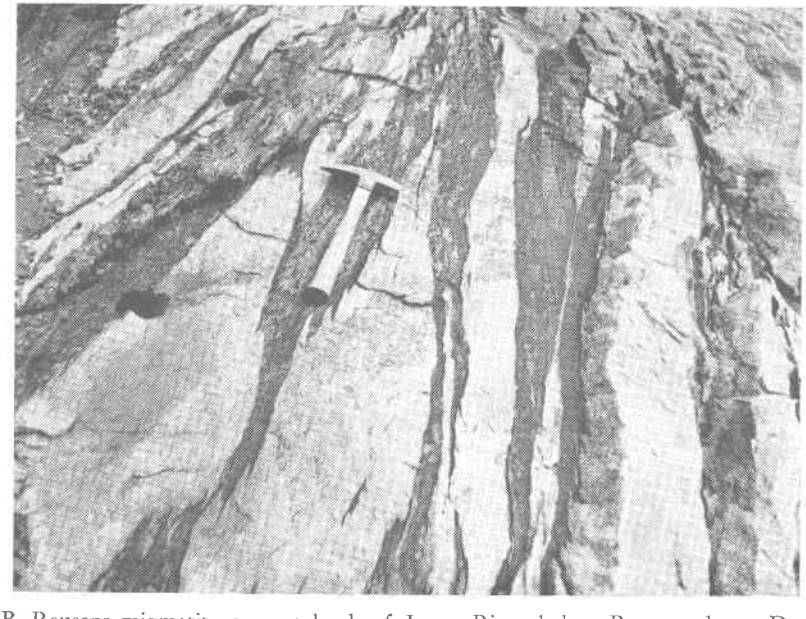

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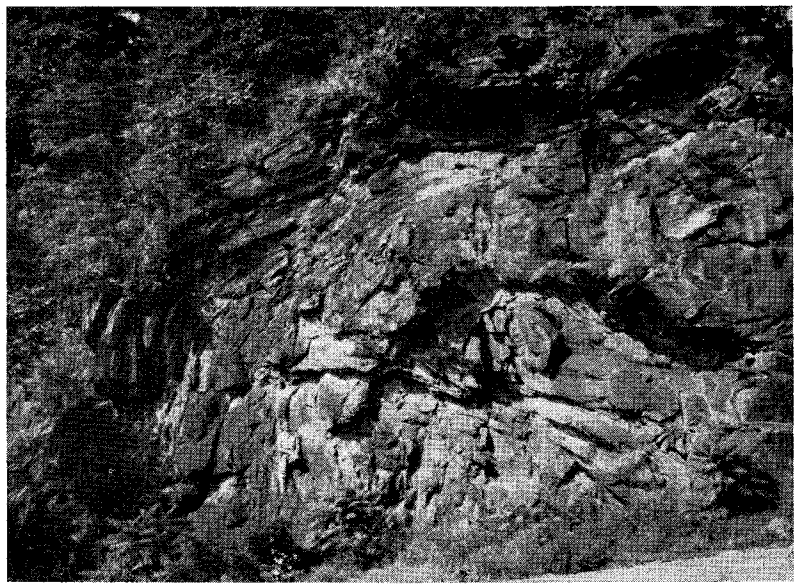
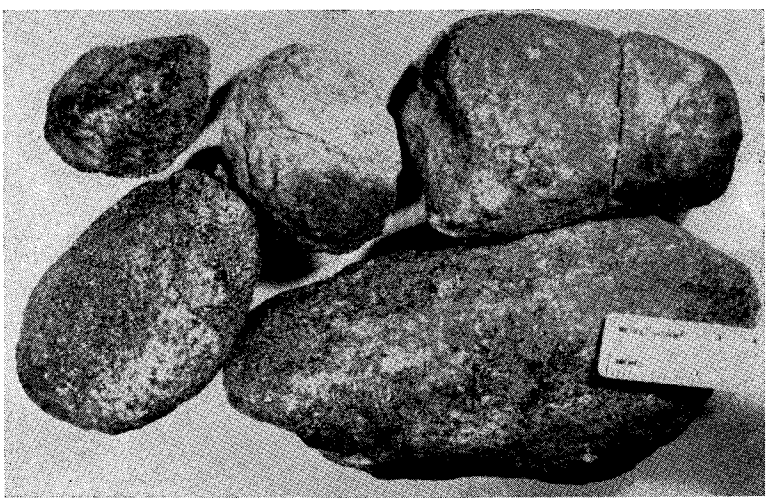
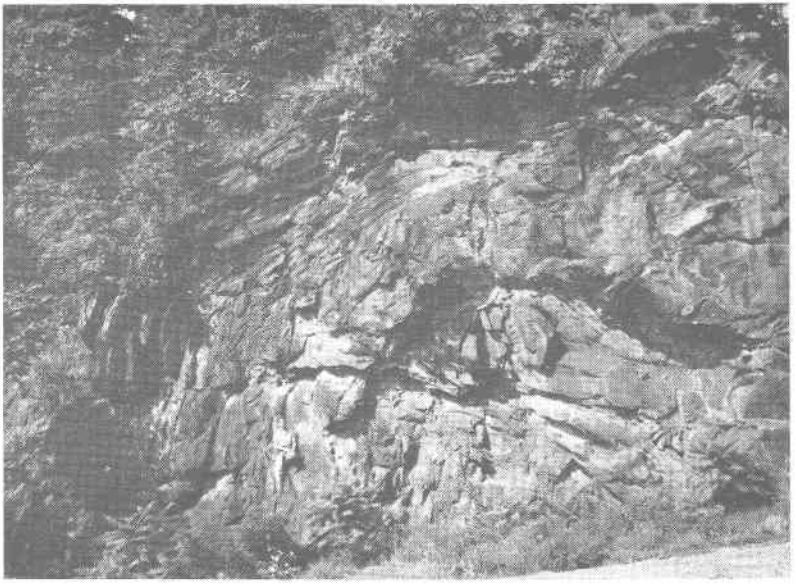


3A. Part of Lynchburg anticline in Lynchburg formation on northeast side of James River opposite Lynchburg.



3B. Cobbles from conglomeratic Lynchburg formation at Ivy Creek half a mile south of Peakland.



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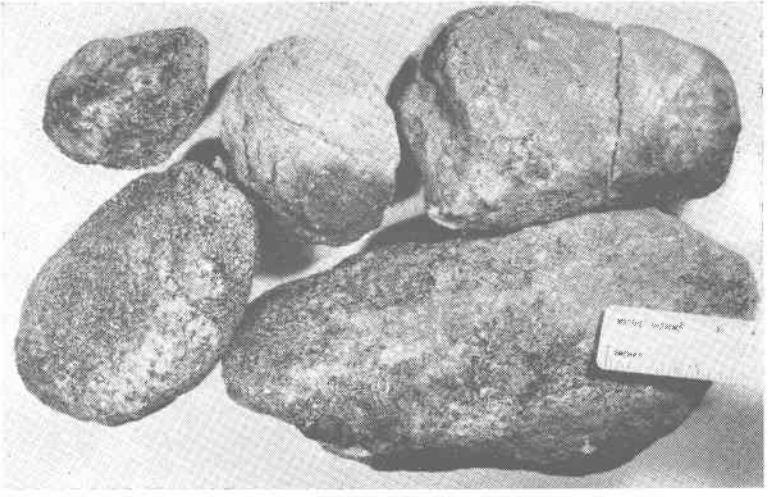
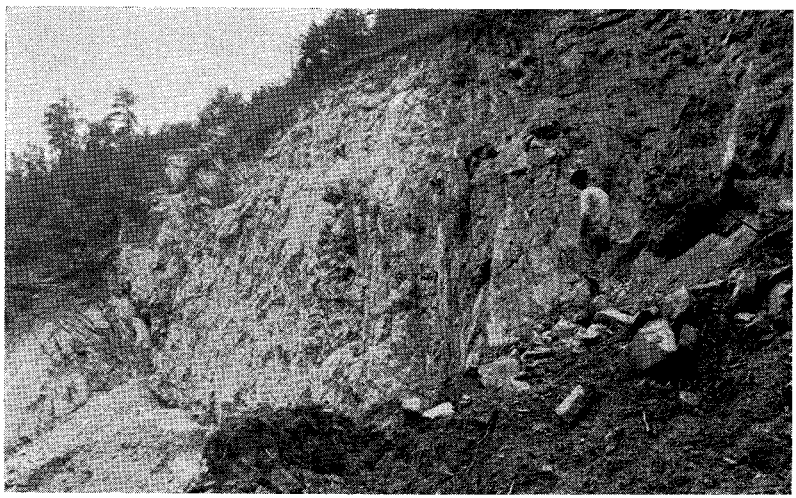
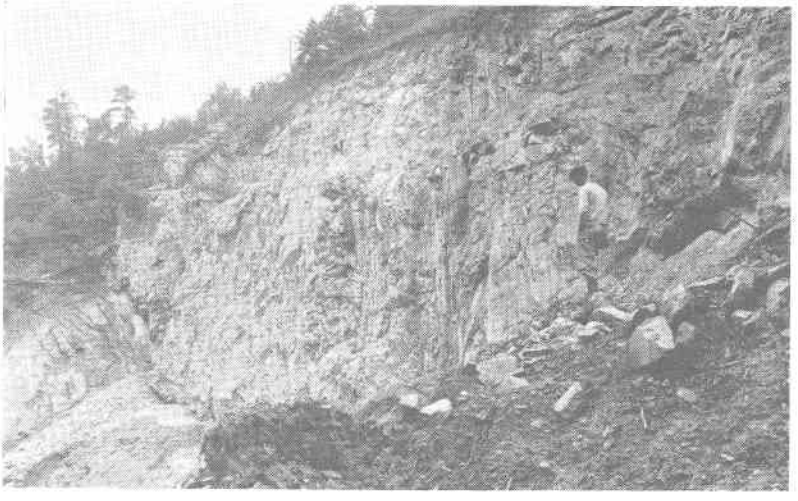


3B. Cobbles from conglomeratic Lynchburg formation at Ivy Creek half a mile south of Peakland.



4A. Quarry in Mount Athos quartzite near mouth of Slippery Branch (Pl. 14 loc. 20).

4B. Chandler phyllite beside U.S. Highway 501 a mile southeast of Lynchburg. Note fissility and tendency to split into lentils.



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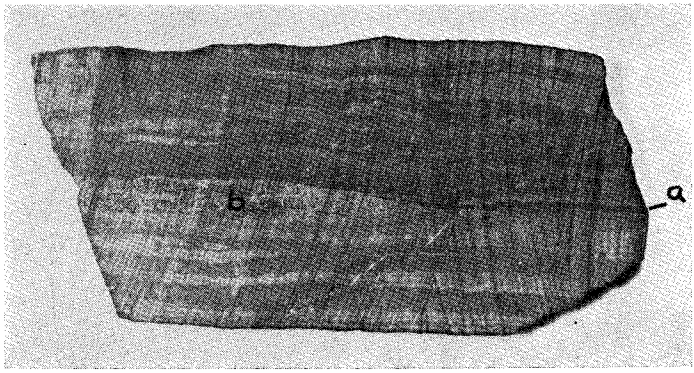
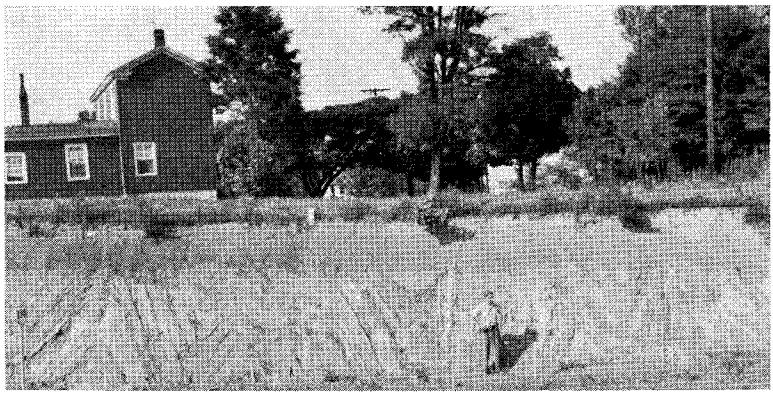
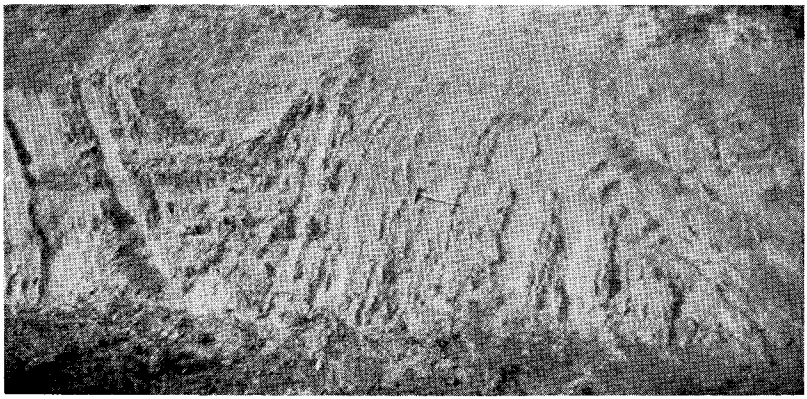


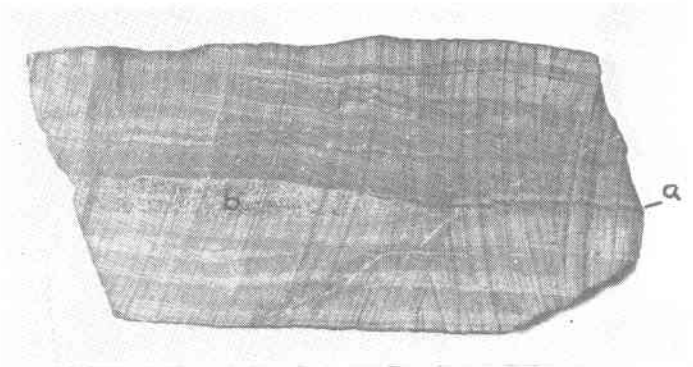
5A. Minor sedimentary features in sawn slab of sandy, argillaceous Arch formation in quarry near mouth of Opossum Creek. Light- and dark-colored layers, a, lap onto ripple ridge, b, and cover truncated laminae in b. Bedding interpreted to be right side up. x ¾.



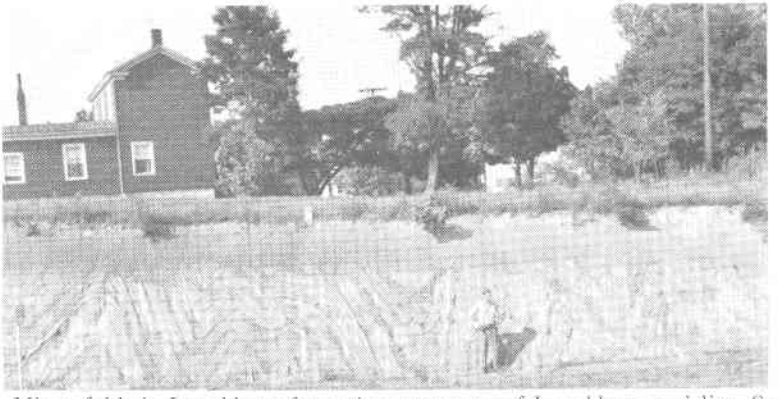
5B. Minor folds in Lynchburg formation near crest of Lynchburg anticline, State Highway 130, Madison Heights.



5C. Close-up of fold in 5B, showing extreme difference in thickness of bed in trough as compared to that on limb of fold. Slip cleavage is developed through trough.

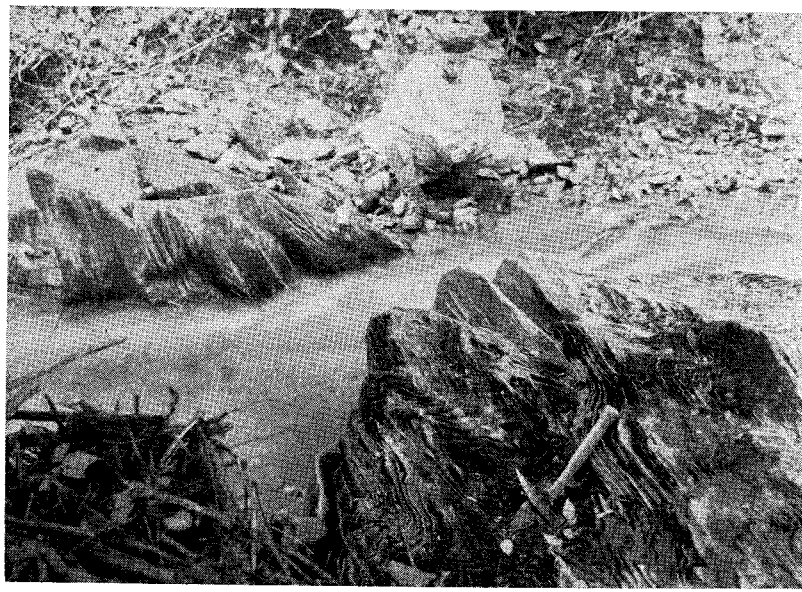


5A. Minor sedimentary features in sawn slab of sandy, argillaceous Arch formation in quarry near mouth of Opossum Creek. Light- and dark-colored layers, a, lap onto ripple ridge, b, and cover truncated laminae in b. Bedding interpreted to be right side up. x ¾.

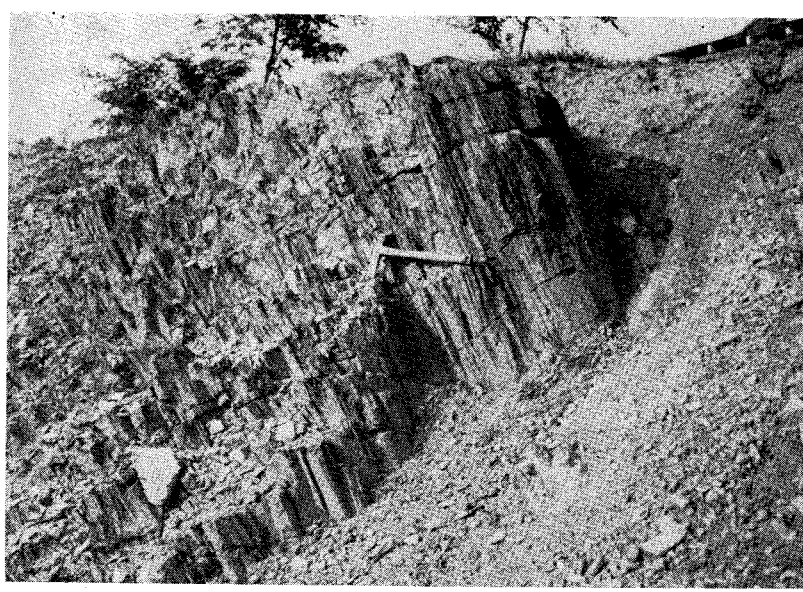


5B. Minor folds in Lynchburg formation near crest of Lynchburg anticline, State Highway 130, Madison Heights.

5C. Close-up of fold in 5B, showing extreme difference in thickness of bed in trough as compared to that on limb of fold. Slip cleavage is developed through trough.



6A. Close, steep-axis folding in Arch marble at Archer Creek near "the Arch."

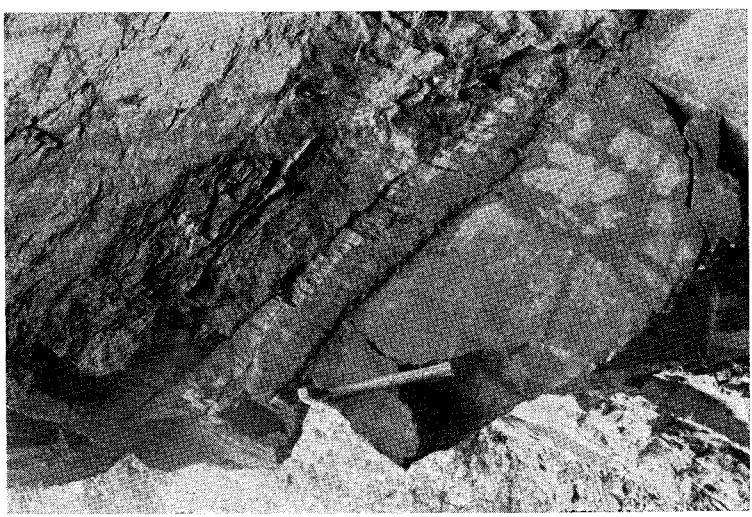


6B. Strong "rodding" lineation in Mount Athos quartzite near Lanes Well Fork 5 miles south of Lynchburg.

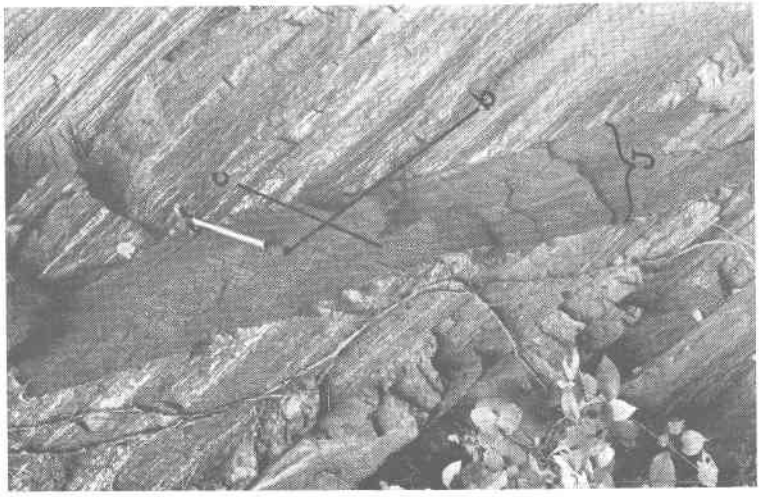
6A. Close, steep-axis folding in Arch marble at Archer Creek near "the Arch."

6B. Strong "rodding" lineation in Mount Athos quartzite near Lanes Well Fork 5 miles south of Lynchburg.

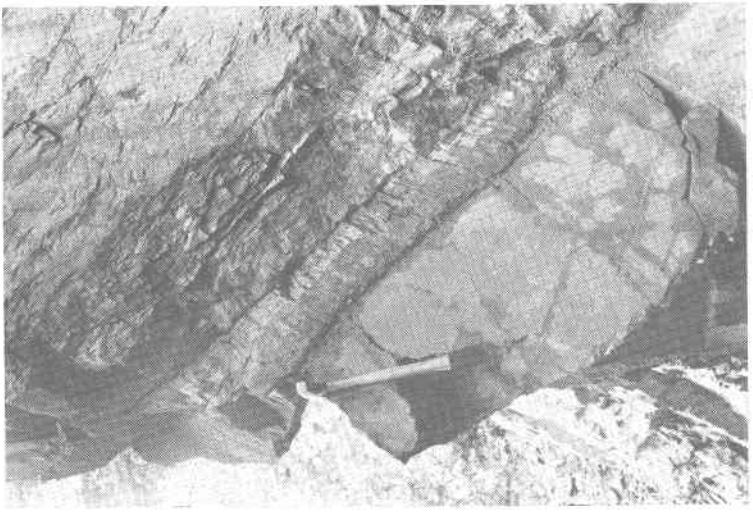
7B. Slip cleagave and bedding on joint surface, J, at same locality as 7A. Cleavage is parallel to line c; bedding is parallel to line b and is upright.



7A. Fracture cleavage (slip cleavage in part) in sandy, argillaceous Arch formation at quarry near mouth of Opossum Creek. Cleavage dips 60° to left; bedding dips 47° to right and is upright.



7B. Slip cleagave and bedding on joint surface, J, at same locality as 7A. Cleavage is parallel to line c; bedding is parallel to line b and is upright.



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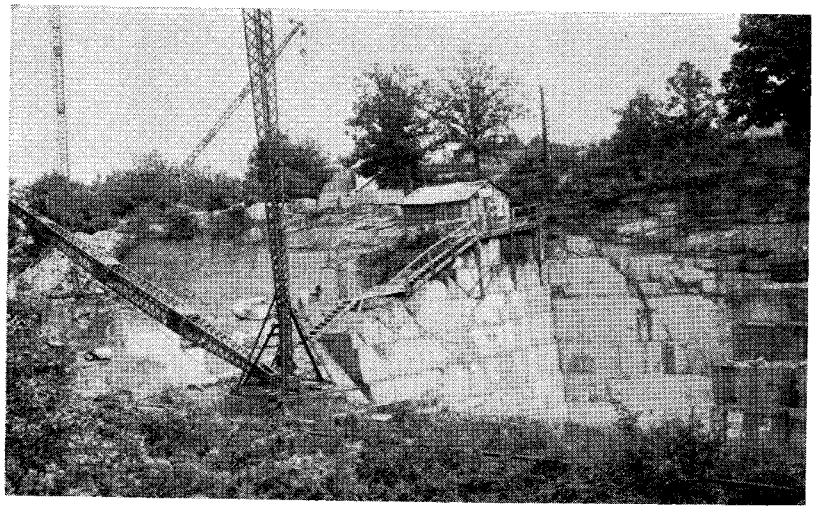
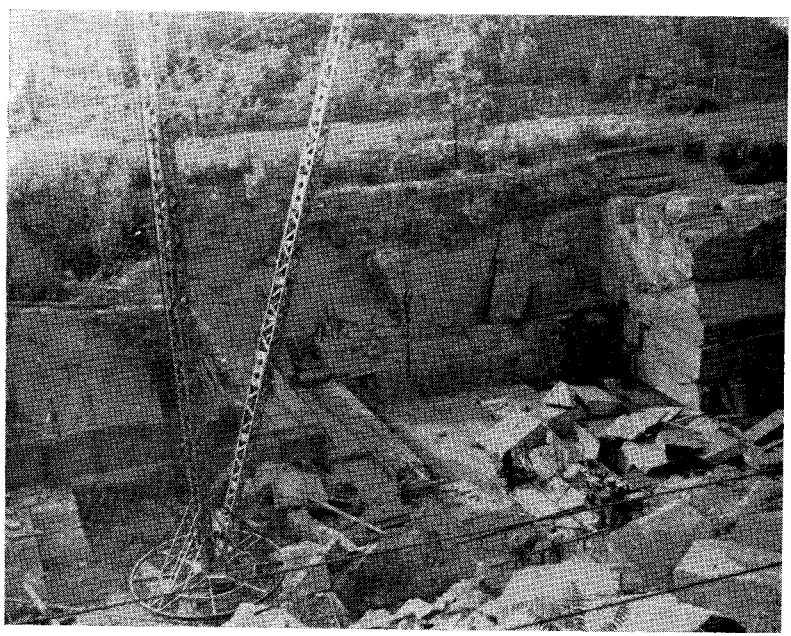
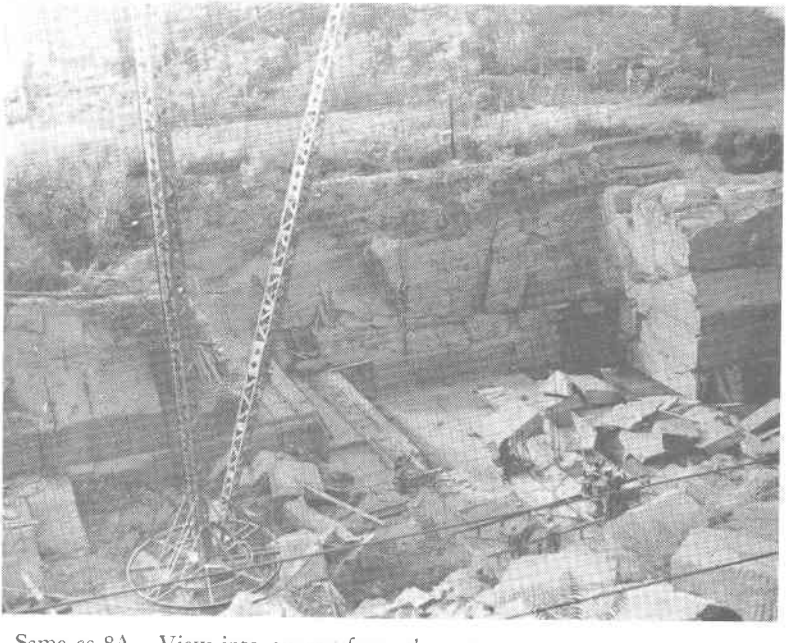


8A. Virginia Greenstone Company Daniel Avenue quarry, Lynchburg. View from west.



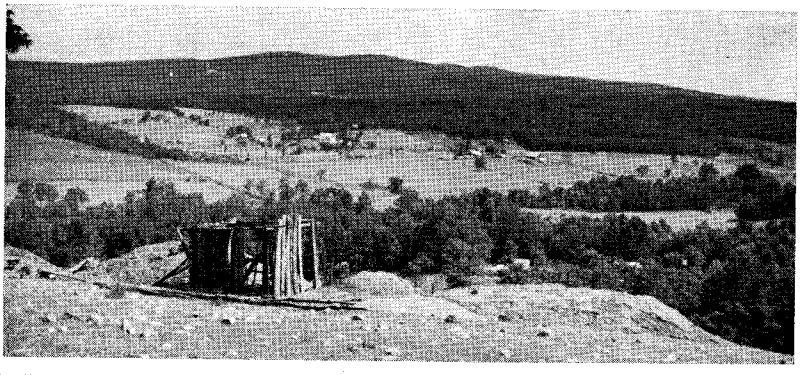
8B. Same as 8A. View into quarry from the east.

8A. Virginia Greenstone Company Daniel Avenue quarry, Lynchburg. View from west.



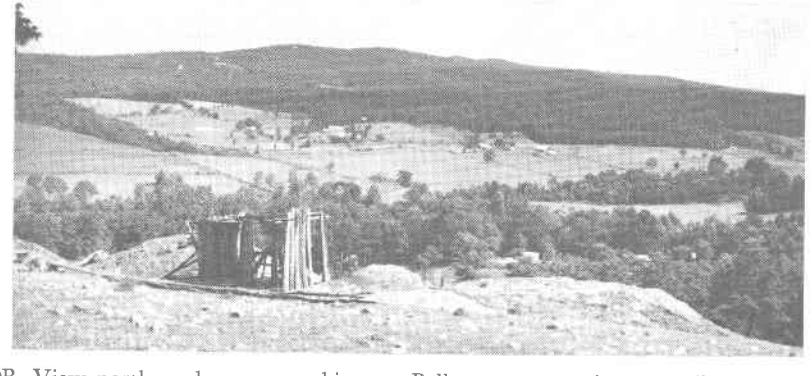
8B. Same as 8A. View into quarry from the east.

9A. Hand windlass over exploratory shaft at the Piedmont manganese mine 5½ miles southeast of Lynchburg.



9B. View northward across workings at Bell manganese mine 5½ miles south of Lynchburg; Candler Mountain in the background.

9A. Hand windlass over exploratory shaft at the Piedmont manganese mine 5½ miles southeast of Lynchburg.



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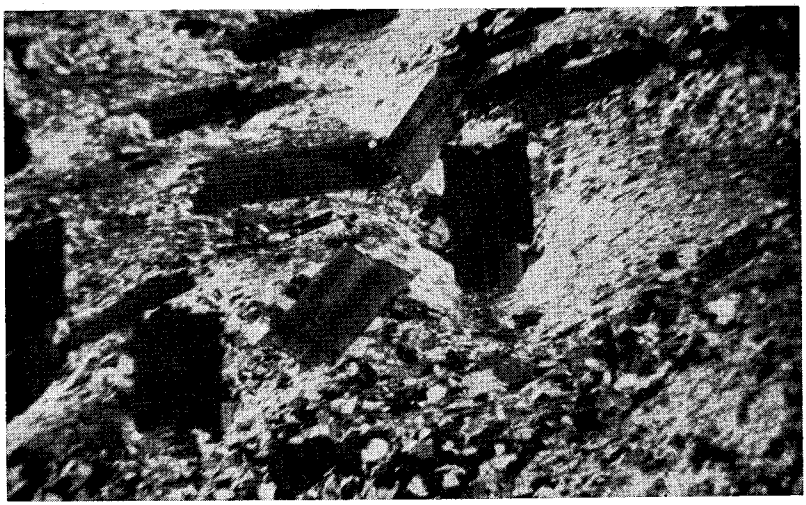
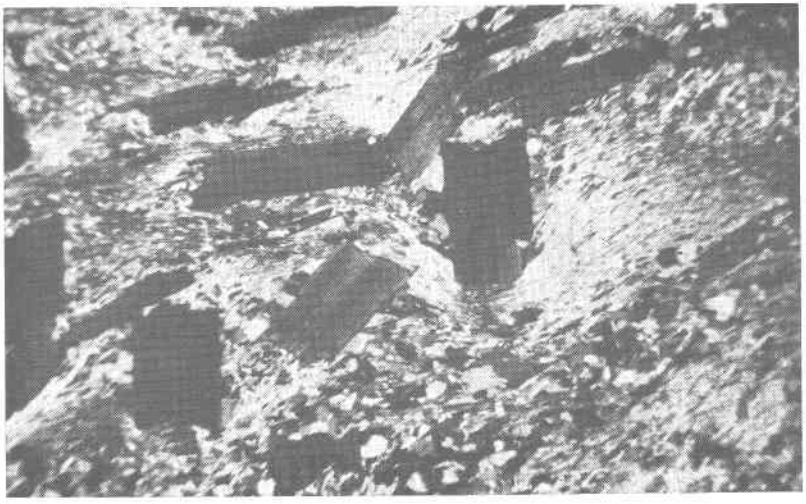


10A. Photomicrograph of porphyroblastic Candler phyllite 0.6 mile southwest of Galts Mill. Chloritoid porphyroblasts push aside and cut across the foliation. Crossed nicols. x 37.

10B. Photomicrograph of garnet with helicitic structure in Candler schist 2 miles southeast of Lynchburg. Garnet is younger than foliation and has been rotated during growth. One nicol. x 52.



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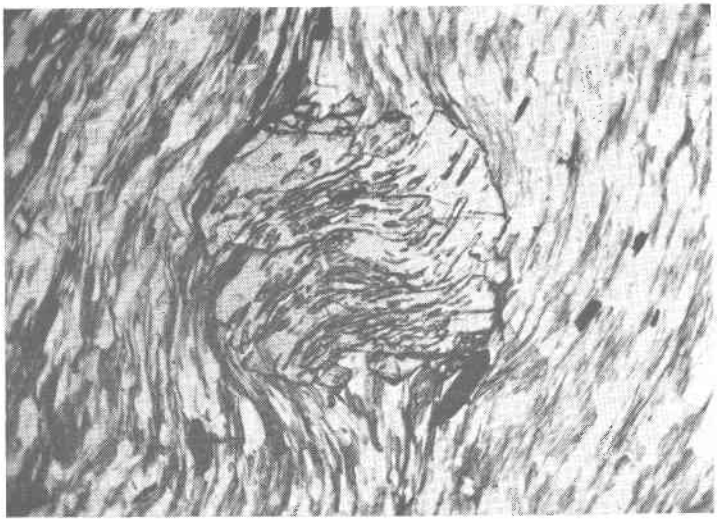

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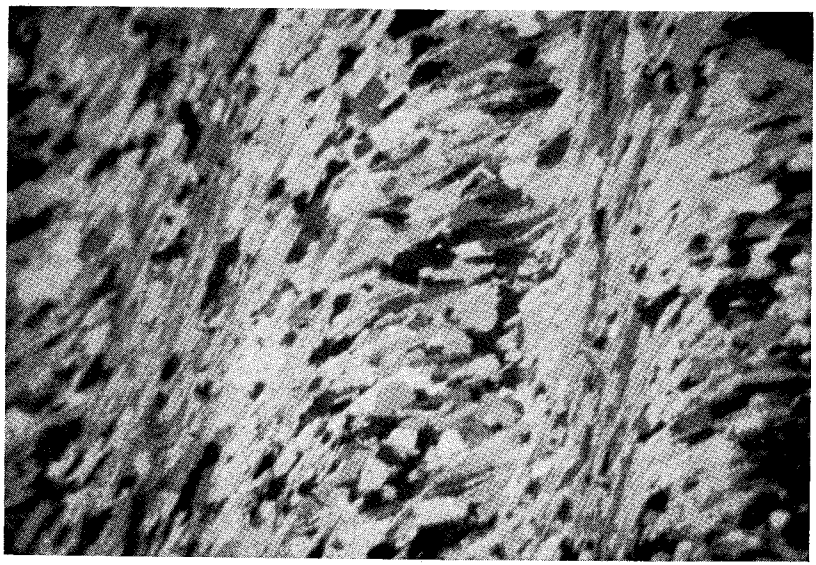
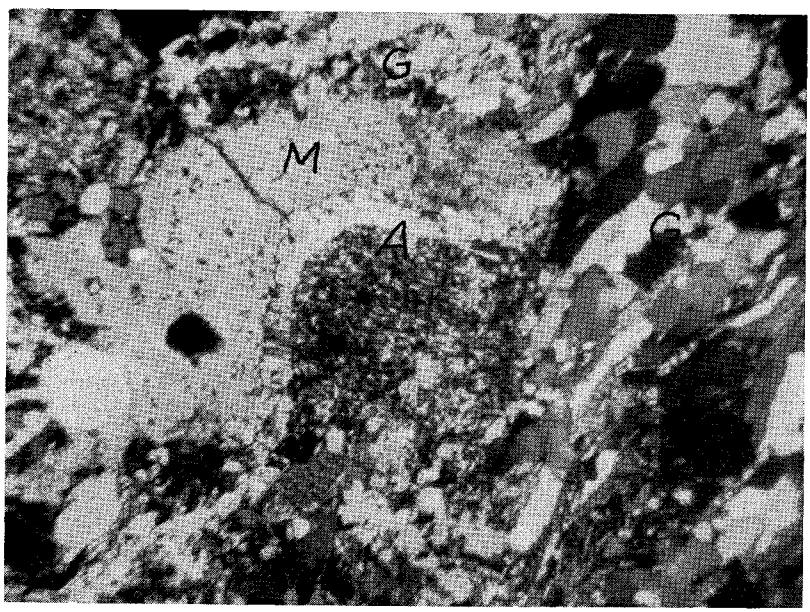
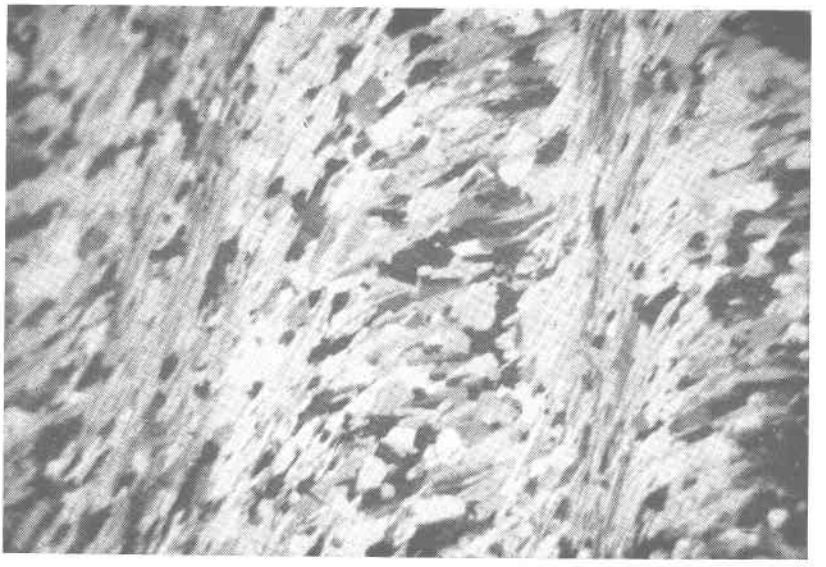


11A. Photomicrograph of simple monoclinal mimetic slip cleavage in Lynchburg formation on east flank of Lynchburg anticline. Crossed nicols. x 21.



11B. Photomicrograph of Marshall gneiss 6½ miles northwest of Lynchburg. Microcline, M, has replaced biotite-quartz gneiss, G, and is being replaced by albite, A. Albite has clear rim, but its interior is filled with tiny mica and clinozoisite inclusions. Crossed nicols. x 47.



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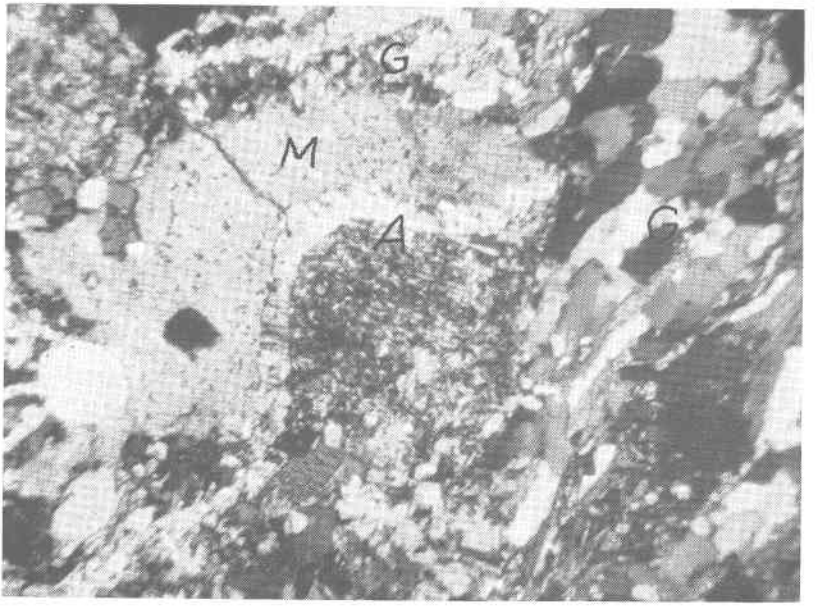

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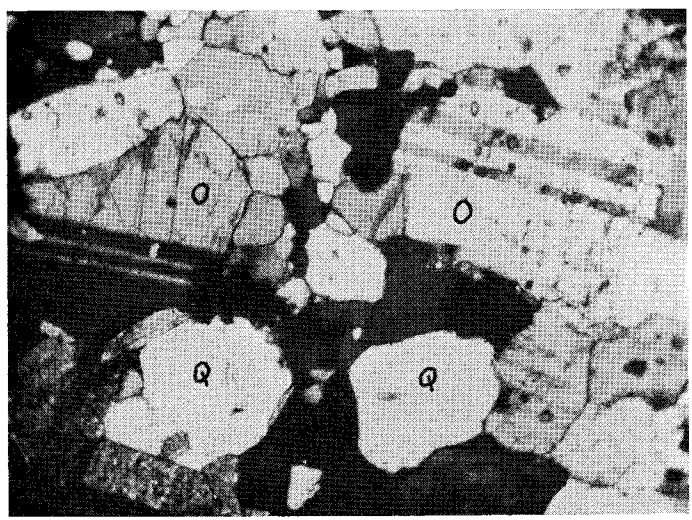
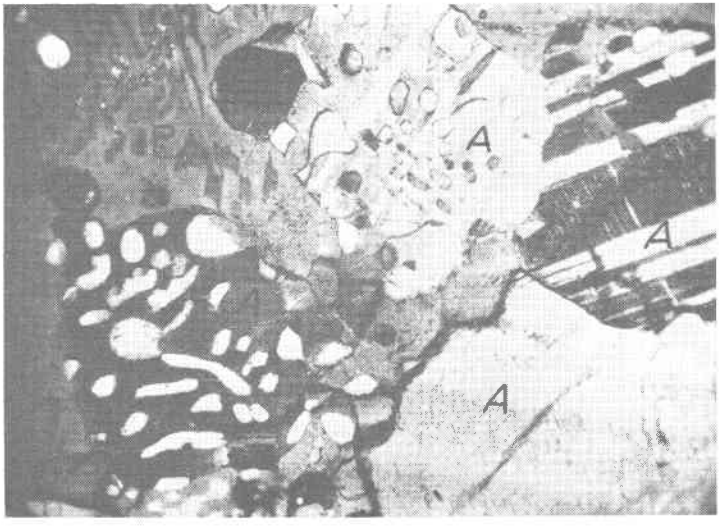
12A. Photomicrograph of hypersthene granodiorite from the Pedlar formation, a mile west of Abert. Andesine, A, and perthite, P, contain clear blebs of quartz. Crossed nicols. x 52.



12B. Photomicrograph of cobble in the conglomerate of the Lynchburg formation at Ivy Creek half a mile south of Peakland. O, Oligoclase; Q, quartz; clear blebs are quartz. Crossed nicols, x 52.



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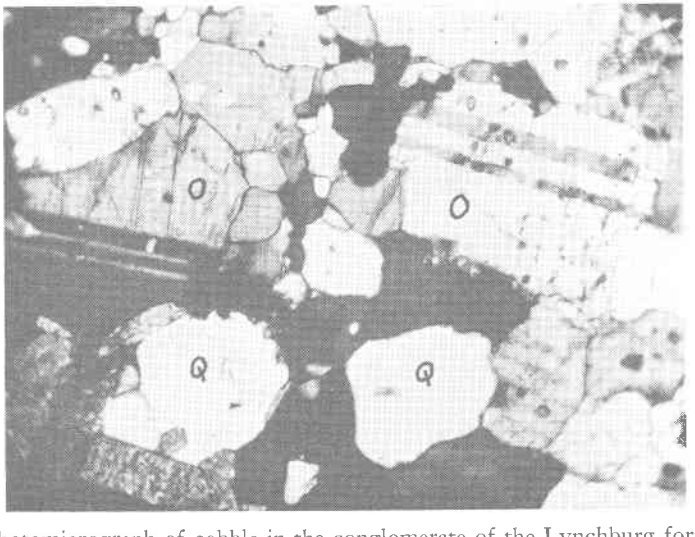

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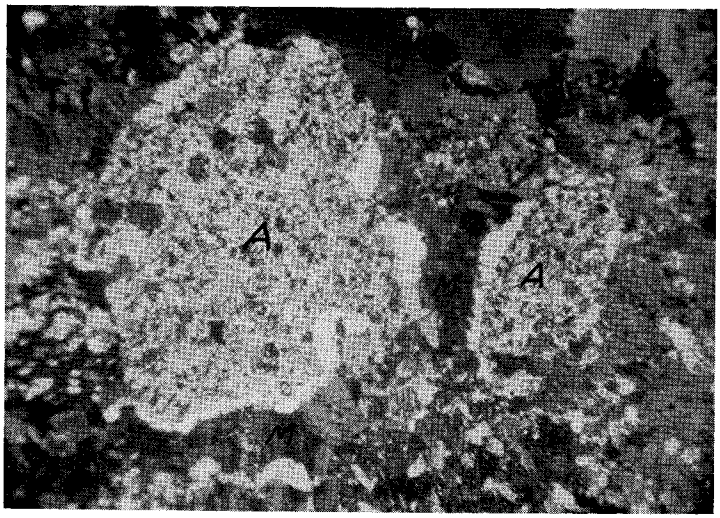
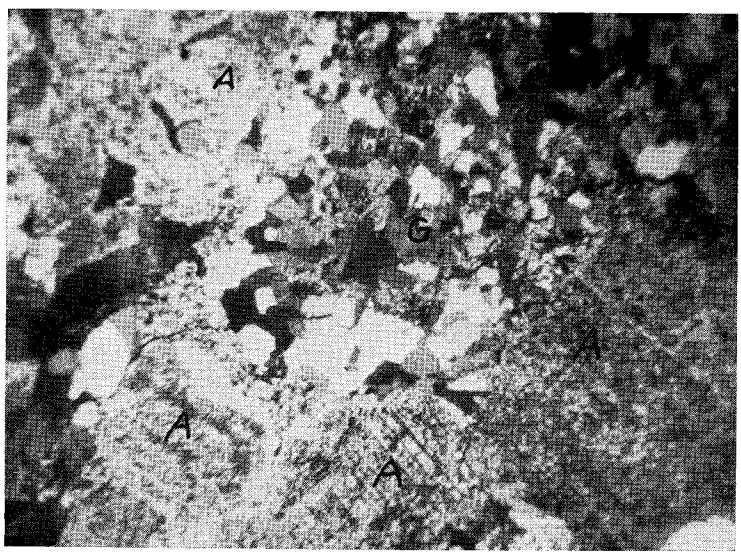
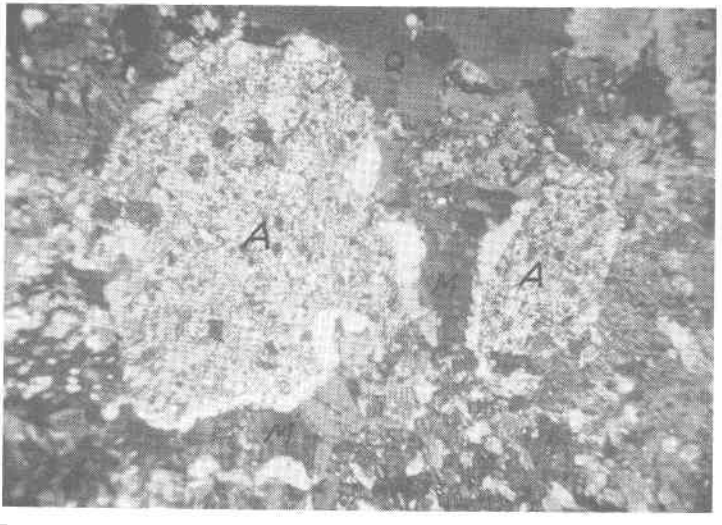


13A. Photomicrograph of Marshall gneiss at Abert. Albite, A, with clear rim and interior filled with tiny muscovite and clinozoisite inclusions, is replacing microcline, M, and quartz, Q. Crossed nicols. x 40.



13B. Photomicrograph of Marshall sodic granite 2½ miles northwest of Reusens. Albite, A, loaded with inclusions, is replacing biotite-quartz gneiss, G. Crossed nicols. x 36.



13A. Photomicrograph of Marshall gneiss at Abert. Albite, A, with clear rim and interior filled with tiny muscovite and clinozoisite inclusions, is replacing microcline, M, and quartz, Q. Crossed nicols. x 40.

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INDEX

PAGE

A

Albitization 11
Analysis of rock
  Chemical 44, 68
  Modal 42-43
Appalachian geosyncline 61, 63
Arch marble 8, 29, 30, 31, 33, 34, 35, 49, 58, 62, 64-68
Archer Creek formation.....78
Arvonia slate 48
Axial plane cleavage.....57, 60

B

Barite 2, 4, 77
"Basement complex" 7
"Basement complex gneiss".....13
"Basic front" 17
Beck Creek fault.....52
Bedding foliation 57
Bell mine 76, 77
Blue Ridge Stone Corporation....65, 76
Blue Ridge uplift.....52
Boudinage 60

C

Candler formation...7, 8, 18, 19, 23, 28, 29, 31-34, 48, 50, 52-56, 60, 62, 64
Catoctin-Blue Ridge anticlinorium 1, 4, 7, 9, 50, 51, 54
Catoctin greenstone....1, 2, 7, 8, 18, 19, 22-26, 31, 38, 41, 45, 48, 50, 53, 56
Catoctin metabasalt or volcanics 5, 61, 62
Catoctin Mountain border fault.....5
Carson mine 77
Carter Mountain belt.....23
Chilhowee group 48
Cockeysville marble 28, 34
Copper ore 4

PAGE

D

Danville Triassic basin.....53
D.B.D. Mining Corporation.....74
"Dejective zones" 4, 52
Deuteric effects 11
Diaphthoresis 54
Dike 47
Drinkard mine 76

E

Epidotization 11
Esmont slates 31, 48
Everona limestone 48, 49
Evington group 1, 2, 5, 7, 28-31, 50, 52, 54, 55

F

Fractional crystallization 25
Fracture cleavage 57, 59
Frederick limestone 49

G

Geosynclines 25
Glenarm series 28, 29
Gold 4
Granite 2, 9
Granitic rocks 71
"Granitized complex" 7
Granitization 1, 13, 17

H

Hardware anticline 45
Harlow Mining Company.....76
Hydrothermal effects 11
Hydrothermal metamorphism 45

I

"Injection complex" 5, 7
Iron ore 2, 78, 79

PAGE

J

Jack Mountain syncline.....37, 52
James River iron and marble belt.5, 6, 7
James River synclinorium..1, 2, 4, 5, 6, 7, 23, 24, 28, 32, 45, 50, 51, 53, 55, 62, 65, 67, 78
Josephine shaft 74, 75
Joshua formation 8, 29, 31, 33, 34 55, 58, 62, 78

L

Lavino Company, E. J.....73
Leets 73, 75, 76
Lerner mine 73
Lerner Mining Company.....74
Loudoun formation 21, 31
Lovingston gneiss 9, 11, 17, 21, 22
Lynchburg anticline 50
Lynchburg formation ..1, 2, 5, 6, 7, 8, 13, 18-23, 30, 31, 38, 39, 40, 41, 45, 46, 50, 52, 53, 56, 57, 59, 60, 61, 62
Lynchburg iron furnace.....64

M

Maddox mine 77
Magmatism 17
Manganese ore 2, 4, 36, 71-78
Marble 2, 4, 64-69
Marshall gneiss 1, 8-13, 16, 17, 21, 22, 48, 50
"Martic line" 5, 54, 56
Martic overthrust 1, 4, 5, 50, 54
Martic thrust block.....5, 54
Metasomatism 17, 40
Migmatism 17
Mimetic slip cleavage.....59
Moneta gneiss 8, 9, 13, 18, 20, 41, 48
Mortimer mine 77
Mount Athos formation..8, 29, 30, 34-37, 62, 64, 65, 69, 72, 73, 77, 78, 79
Mount Athos mine.....75
Myers Chemical Company.....74
Myers mine 73
Mylonitization 32, 53, 55

PAGE

N

National Paint and Manganese Company 73
Neighbors mine 76
Neomineralization 25, 57

O

Ophiolite 25
Otter River Mining Company.....76
Oxford mine 78
Oxford Mining and Manganese Company 74
Oxford shaft 74

P

Palingenesis 17
Pedlar formation ..1, 8, 9, 10, 12, 17, 48
Pelier schist ..8, 29, 30, 31, 34, 35, 36, 62
"Phyllonite" 32
Phyllonization 54
Piedmont Manganese Company.....74
Piedmont mine 68, 72, 73
Pillow lavas 24
Pribble mine 77
Pyrite 4

R

Radiolarian cherts 24
Recrystallization 25
Retrograde metamorphism 5, 53
Retrogression 54, 55
Reusens migmatite 1, 8, 9, 12-15, 17, 18, 22, 38, 50, 60
Rockfish conglomerate.....5, 21, 22, 61
Rockydale Stone Service Company 65, 66
Roseland anorthosite 9
Ross mine 78
Round Mountain syncline.....37

S

Sand 2, 71
Saunders mine 72
Sericitization 11
Sherwill anticline 1, 2, 7, 45, 50, 52, 53, 56, 61

PAGE

Silification 11
Sill-like bodies 2, 20
Slate 4
Slip cleavage 58, 59, 60
Slipper Creek Greenstone 8, 26, 28, 29, 34, 36, 37, 49, 52, 53, 62
Smithson 75
Southern Mines and Metal Company.75
Spilitic lavas 24
Swift Run formation.....48, 61

T

Tussocky dome 56

V

Virginia Blue Ridge complex.....1, 7, 11, 18, 21, 22, 48, 61
"Virginia Greenstone" 2, 46, 69, 70
Virginia Greenstone Company, Inc. 69, 70
Virginia Ores Corp.....77
Volcanics 22
Volcanism 24, 36, 37

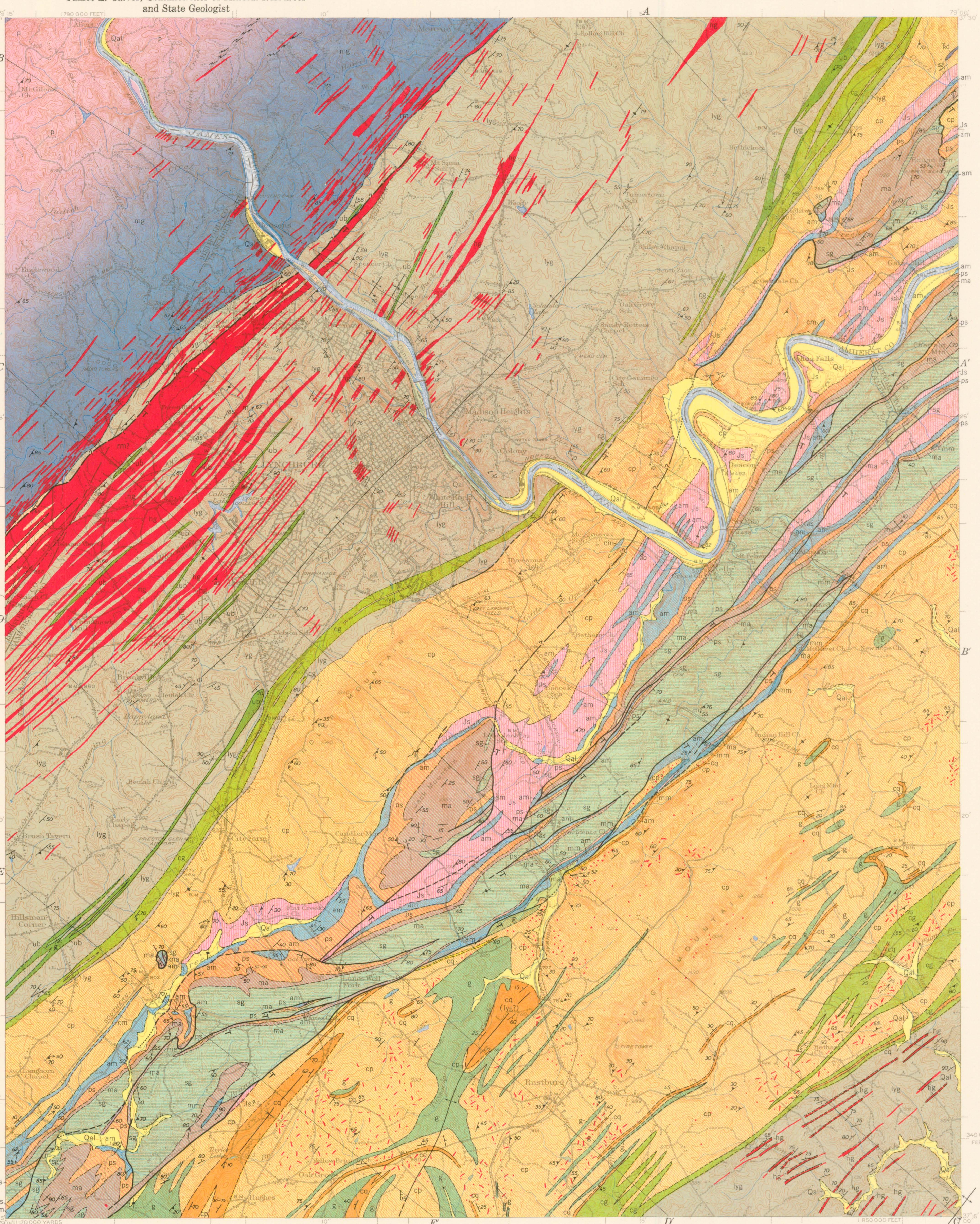
W

Whitman mine 75
Wissahickon formation ...28, 34, 53, 54

Z

Zonation 17

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



Base from U. S. Geological Survey
topographic map

Geology by Wm. R. Brown, assisted in part by H. C. Sunderman
Mapped 1940-41, 1946-47, 1950

GEOLOGIC MAP AND STRUCTURE SECTIONS OF THE LYNCHBURG QUADRANGLE, VIRGINIA

Scale 1:62,500

Contour interval 20 feet
Datum is mean sea level

EXPLANATION

Qal — Alluvium (QUATERNARY)

Td — Diabase (TRIASSIC)

EVINGTON GROUP (LOWER PALEOZOIC(?))

sg — Slippery Creek greenstone
(Dark green to gray, schistose to gneissose lava flows; amygdaloidal in part. Tuffaceous (?) schist at base common.)

ma, mm — Mount Athos formation
(Quartzite, quartzitic conglomerate, and mica schist. White marble member, mm.)

ps — Peller schist
(Tan sericite-quartz schist, chloritoid-quartz-sericite schist. Commonly characterized by biotite porphyroblasts.)

am — Arch marble
(Fine- to medium-grained, blue-gray, schistose marble; blue-gray calcareous schist; arenaceous blue-gray marble.)

Js — Joshua schist
(Blue-gray phyllite and fine-grained schist; calcareous schist and schistose marble. Biotite porphyroblasts common.)

cp, cq, cm — Candler formation
(Lustrous, gray-green phyllite and fine- to coarse-grained schist. Garnet-bearing facies shown by red dots; staurolite-bearing facies shown by red cross hatches. Mica quartzite members, cq. Blue-gray marble members, cm.)

g — Greenstone
(Includes greenstones of uncertain age and origin. Some may be intrusive, but most resemble Catoctin greenstone and probably belong to the Catoctin period of vulcanism.)

PRECAMBRIAN

cg — Catoctin greenstone
(Dark green, fine-grained biotite-epidote-chlorite-amphibole schist and gneiss. Amygdaloidal in part.)

ub — Ultrabasics
(Chlorite-amphibole schists, serpentine, peridotite, and soapstone.)

lyg, hg — Lynchburg formation
(Gray biotite-quartz gneiss, quartz-mica schist, and graphitic schist. hg, hornblende gneiss and amphibolite in and apparently younger than enclosing schists and gneisses.)

VIRGINIA BLUE RIDGE COMPLEX

p — Pedlar formation
(Dark greenish gray, coarse-grained granodiorite. Contains hypersthene and blue quartz.)

mg — Marshall gneiss
(Medium to dark gray, coarse-grained biotite-quartz monzonite gneiss. Feldspar-mica augen in parts.)

rm — Reusens migmatite
(Migmatite of Marshall gneiss in dark dioritic hornblende gneiss. The hornblende gneiss appears older than the injections of Marshall gneiss.)

Formational contact, dashed where approximated, dotted where buried.

Thrust fault, dashed where approximated, dotted where buried.

Doubtful or probable fault.

Anticline

Syncline

Strike and dip of beds

Strike variable

Bedding vertical

Bedding overturned

Horizontal beds

Strike and dip of foliation

Vertical foliation

Bearing and plunge of foliation-bedding intersections

Bearing and plunge of axes of minor folds and crinkles

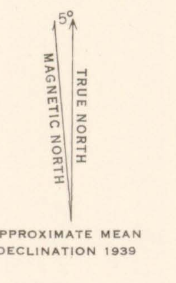
Bearing and plunge of mineral streakings

Strike and dip of bedding and foliation, and plunge of foliation-bedding intersections.

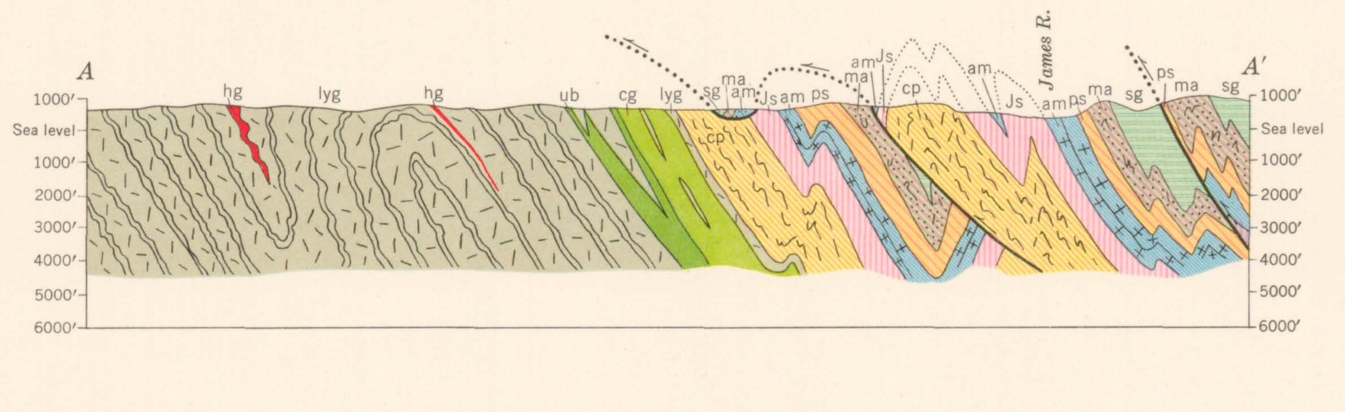
Strike and dip of joints

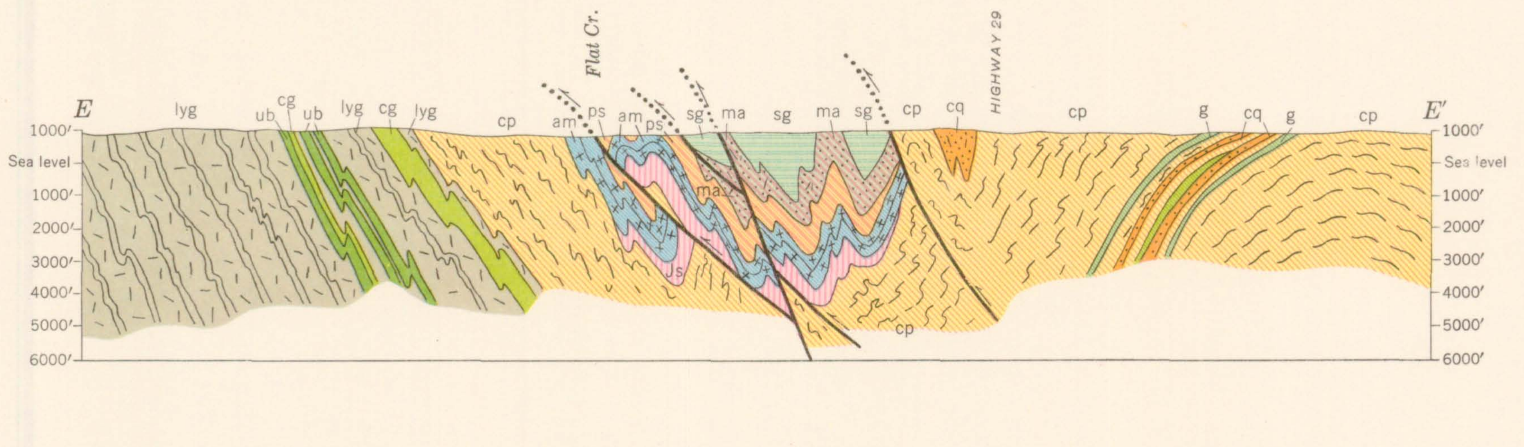
Zone of shearing

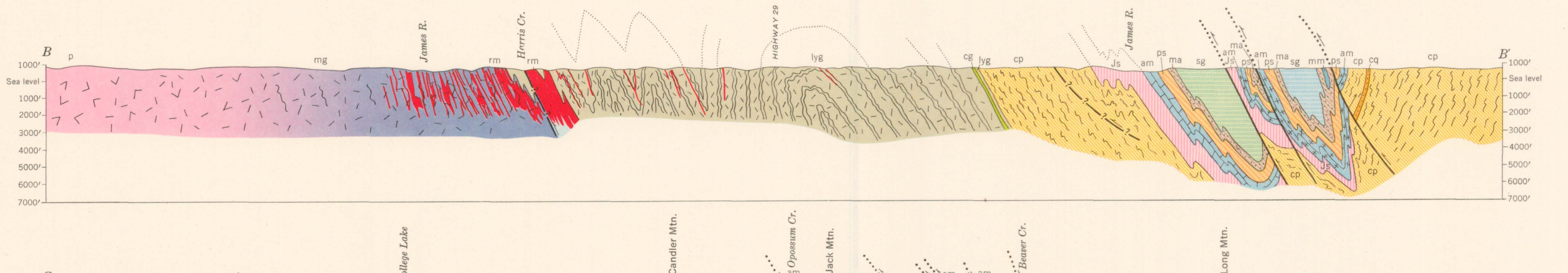
Mine or quarry

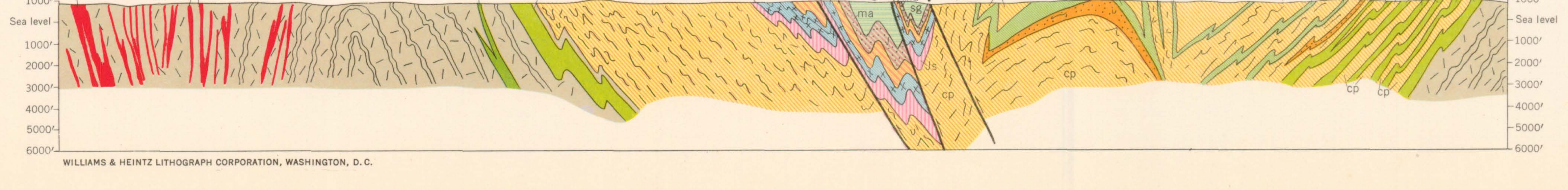


APPROXIMATE MEAN DECLINATION 1950









No vertical exaggeration in sections

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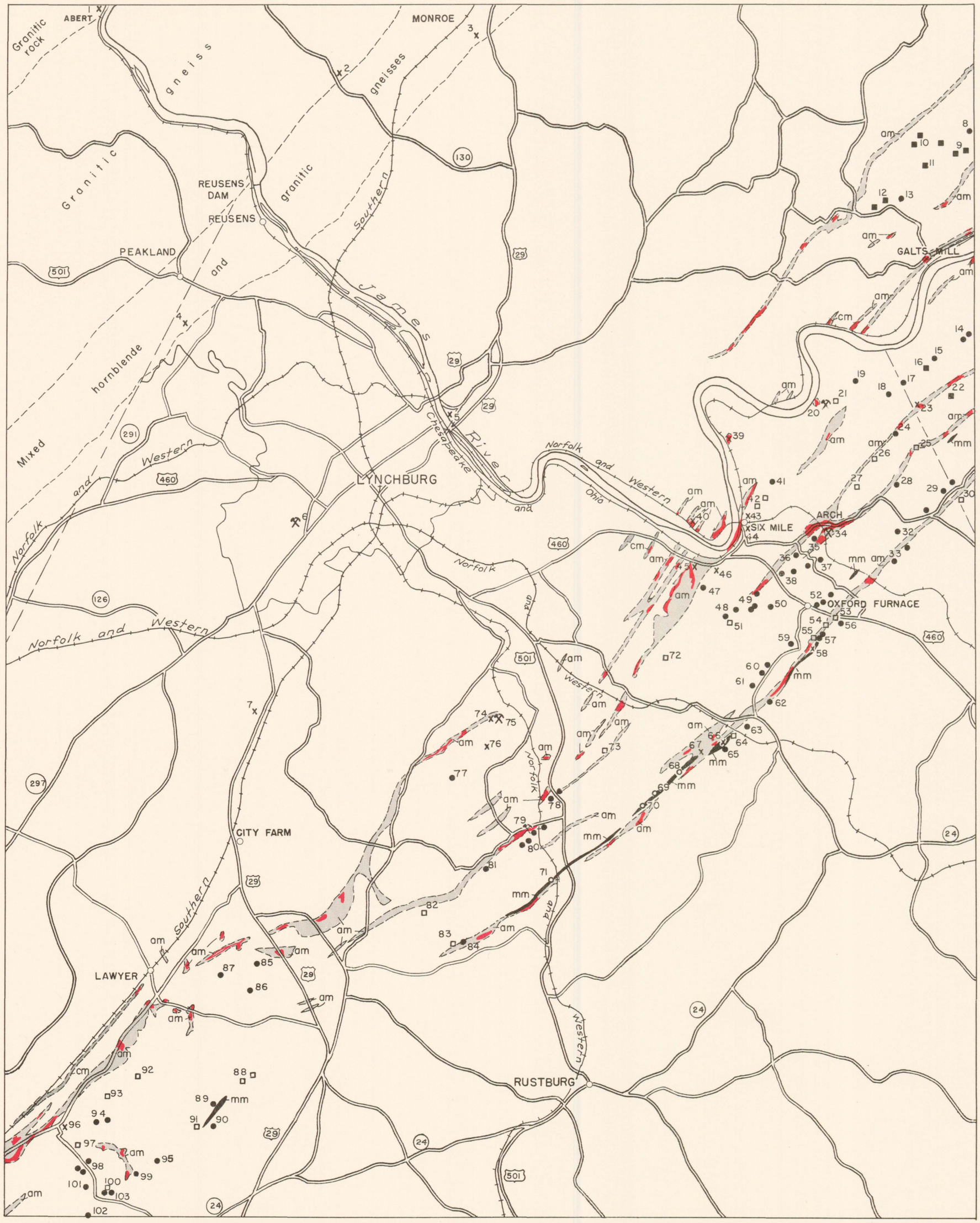


MAP SHOWING DISTRIBUTION OF MINERAL RESOURCES IN THE LYNCHBURG QUADRANGLE, VIRGINIA

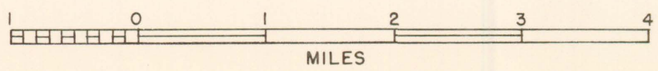
MINES, PROSPECTS, AND QUARRIES

1. C. & O. granite quarry
2. Granite quarry (quartz monzonite)
3. Hornblende gneiss-granite quarry (Reusens migmatite)
4. Hornblende gneiss quarry (Reusens migmatite)
5. Lynchburg gneiss quarry
6. Virginia Greenstone Co. quarry
7. Greenstone pit
8. Manganese prospect
9. Round Top iron mines (hematite)
10. Round Top iron mines (hematite)
11. Round Top iron mines (hematite)
12. Lone Pine iron mine (hematite)
13. Manganese prospect
14. Chestnut Mountain (Woodson) manganese prospect
15. Chestnut Mountain (Woodson) manganese prospect
16. Chestnut Mountain iron mine (hematite)
17. Joshua Creek manganese mine
18. Manganese prospect
19. Mount Athos manganese prospect
20. State quartzite quarry
21. Iron mine (limonite)
22. Iron prospect (hematite)
23. Marble quarry (Arch fm.)
24. Manganese prospect
25. Iron prospect (limonite)
26. Iron prospect (limonite)
27. Iron mine (limonite)
28. Manganese prospect
29. Manganese prospects
30. Iron mine (limonite)
31. Manganese prospect
32. Old Tavern manganese prospects
33. Ryan manganese prospects
34. Rockydale Stone Service Corp. marble quarry (Arch fm.)
35. Leets (Whitman) manganese mine
36. Leets-Trent manganese prospects
37. Manganese prospect
38. Manganese prospects
39. Marble quarry (Arch fm.)
40. N. & W. marble quarry (Arch fm.)
41. Manganese prospect
42. Iron mines (limonite)
43. Quartzite quarry
44. Quartzite quarry
45. Marble-schist quarry (siliceous Arch fm.)
46. Quartzite quarry
47. Manganese prospect
48. Drinkard (Hebert or Adams) manganese prospects
49. Manganese prospects
50. Manganese prospects
51. Iron mine (limonite)
52. Ryan manganese prospects
53. Oxford or Ross iron mine (limonite)
54. Piedmont iron mine (limonite)
55. Piedmont iron mine (limonite)
56. Piedmont (Lerner or Myers) manganese mine
57. Piedmont (Lerner or Myers) manganese mine
58. Quartzite quarry
59. Manganese prospect
60. Harvey manganese mine
61. Manganese prospect
62. Manganese prospect
63. Lindsay manganese prospects
64. Iron prospects (limonite)
65. Lindsay manganese prospects
66. Lindsay marble pit (Mount Athos fm.)
67. Lindsay marble pit (Arch fm.)
68. Lindsay barite prospect
69. Carson barite mine
70. Carson barite mine
71. Neighbours barite mine
72. Iron prospect (limonite)
73. Iron prospect (limonite)
74. Quartzite quarry
75. Quartzite quarry
76. Quartzite quarry
77. Jack Mountain manganese prospect
78. Bethel (Stevens) manganese prospect
79. Blue Ridge Stone Corp. marble quarry (Arch fm.)
80. Neighbours manganese mine
81. Manganese prospect
82. Iron prospect (limonite)
83. Dodson iron mine (limonite)
84. Dodson manganese prospect
85. Bell manganese mine
86. Manganese prospect
87. Maddox manganese mine
88. McGehee iron prospects (limonite)
89. McGehee (Arthur) manganese mine
90. Manganese prospect
91. Iron prospect (limonite)
92. Iron prospect (limonite)
93. Iron prospect (limonite)
94. Mortimer (Wood) manganese mine
95. Manganese prospect
96. Quartzite quarry
97. Iron mine (limonite)
98. Mortimer (Wood) manganese mine
99. Manganese prospect
100. Mortimer iron mine (limonite)
101. Mortimer (Wood) manganese mine
102. Pribble (Mitchell-Leghorn) manganese mine

(Note: Names and locations in part from Espenshade, 1954, Plate 2)

EXPLANATION OF SYMBOLS

mm, Mount Athos white marble

am, Arch blue-gray marble
cm, Candler blue-gray marble
Outcrop of marble

- Manganese mine or prospect
- Barite mine or prospect
- Iron mine or prospect (hematite)
- Iron mine or prospect (limonite)
- Stone quarry
- Small stone quarry or pit