COMMONWEALTH OF VIRGINIA

DEPARTMENT OF CONSERVATION
AND ECONOMIC DEVELOPMENT

DIVISION OF MINERAL RESOURCES

GEOLOGY AND MINERAL RESOURCES OF ROCKINGHAM COUNTY

WILLIAM B. BRENT

BULLETIN 76

VIRGINIA DIVISION OF MINERAL RESOURCES

James L. Calver
Commissioner of Mineral Resources and State Geologist

CHARLOTTESVILLE, VIRGINIA
1960

COMMONWEALTH OF VIRGINIA

DEPARTMENT OF CONSERVATION
AND ECONOMIC DEVELOPMENT

DIVISION OF MINERAL RESOURCES

GEOLOGY AND MINERAL RESOURCES OF ROCKINGHAM COUNTY

WILLIAM B. BRENT

BULLETIN 76

VIRGINIA DIVISION OF MINERAL RESOURCES

James L. Calver
Commissioner of Mineral Resources and State Geologist

CHARLOTTESVILLE, VIRGINIA
1960

Commonwealth of Virginia

Department of Purchases and Supply

Richmond

1960

CONTENTS

CONTENTS—Continued

CONTENTS—Continued

CONTENTS—Continued

CONTENTS—Continued

ILLUSTRATIONS

TABLES

PAGE

GEOLOGIC SECTIONS

PAGE

GEOLOGY AND MINERAL RESOURCES OF ROCKINGHAM COUNTY

By

WILLIAM B. BRENT

ABSTRACT

Rockingham County is in the northwestern part of Virginia and extends from the top of the Blue Ridge on the southeast to West Virginia on the northwest. Its boundaries enclose an area of 871 square miles, mostly within the Appalachian Valley and Ridge province.

Bedrock of the county ranges in age from Precambrian to Mississippian but consists principally of Cambrian, Ordovician, and Devonian rocks. The rocks of sedimentary origin have a maximum thickness of 25,000 feet. The Precambrian rocks are in the Blue Ridge to the southeast and the Mississippian rocks occur in the western part of the county.

Precambrian rocks of the Blue Ridge consist of a complex of igneous and metamorphic rocks which is overlain unconformably by the thin Swift Run formation and by Catoctin greenstone. On the northwest side of the Blue Ridge are Lower Cambrian sandstones, shales, and quartzites succeeded by dolomites, limestones, and some interbedded shales. The central part of the county, the Shenandoah Valley, contains principally Cambrian and Ordovician limestones, dolomites, shales, and thin sandstones. Silurian and Devonian rocks occur in this area within the Massanutten Ranges. The western part of the county consists mainly of Devonian and Mississippian sandstones and shales, but Silurian and Ordovician rocks have small areas of exposure. A few basic intrusives in the form of dikes and sills and one plug, probably of Triassic age, cut the Cambrian and Ordovician sedimentary rocks.

Rockingham County is in the Appalachian Mountains and its structural features, mostly of late Paleozoic age, are characteristic of that mountainous region. There are many relatively small folds in the Blue Ridge but the rocks dip generally to the northwest. Many faults occur but no large overthrusts are present in this area. In the central part of the county are northeast-southwest trending Cambrian and Ordovician rocks that have been complexly folded and faulted. A major structure is the Massanutten synclinal complex that extends completely

across the county. The southwestern end of topographic prominence of the Massanutten Ranges is near Penn Laird and Montevideo. The Pulaski-Staunton thrust fault reaches almost across the county; the northeastern terminus is about 3 miles south of the Shenandoah County boundary. Roughly parallel to and about 10 or 12 miles northwest of the Pulaski-Staunton fault is a major thrust fault, the Little North Mountain fault, which completely traverses Rockingham County. Northwest of the Little North Mountain fault is Little North Mountain, which consists principally of steeply dipping to overturned Ordovician, Silurian, and Devonian rocks. Northwest of Little North Mountain there is some close folding but much of the area consists of broad gentle flexures. Faulting is confined mainly to small reverse and normal faults, too small to be shown on the geologic map of the county.

Rockingham County contains deposits of iron, manganese, and zinc ores, limestone, building stone, and natural gas. Oxides of iron and manganese occur in irregularly shaped bodies in the residuum of Lower Cambrian formations at the northwest foot of the Blue Ridge. These deposits are thought to represent concentrations from original carbonate minerals disseminated in the bedrock. There are many zinc showings in Ordovician carbonate rocks, and one active zinc mine in a breccia in Beekmantown dolomite near Timberville. High-calcium limestone and limestones suitable for dimension stone occur extensively in the county. Most of the active quarries produce limestone or dolomite for concrete aggregate, roadstone, or agricultural stone. Several natural gas wells have been drilled in the northwestern part of the county, near Bergton, but there is no gas production at present. Abundant water supplies seem to occur in the vicinity of the South Fork of Shenandoah River.

INTRODUCTION

LOCATION OF THE AREA

Rockingham County is in the northern part of Virginia on the western edge of the state (Fig. 1). Virginia counties bordering Rockingham are: Augusta on the south, Albemarle and Greene on the east, and Page and Shenandoah on the north. Adjoining West Virginia counties are Pendleton and Hardy. The county lies between lines of longitude 78° 25′ and 79° 15′ west and lines of latitude 38° 10′ and 39° north. This area is shown on eleven 15-minute quadrangle maps: Broadway, Harrisonburg, Elkton, Ft. Seybert, Parnassus, Mt. Jackson, Orkney Springs, Petersburg, W. Va.-Va., Waynesboro, University, and Madison.

SCOPE AND PURPOSE OF REPORT

The geology of the county, the stratigraphy, structure, and mineral resources are discussed. Special mention is made of the water resources. The report is intended to serve as a guide to the geology of the county, and as an aid to an understanding of the various features and materials of the earth. Previous publications have dealt with various parts of the county and have emphasized specific topics. This report synthesizes the previous work and the work of the writer into a single volume.

ACKNOWLEDGEMENTS

Parts of Rockingham County were mapped previously but completion of the field work and preparation of the report have been made possible by James L. Calver, Commissioner of Mineral Resources and State Geologist of Virginia. A report on the area around Elkton was written by P. B. King and published by the U. S. Geological Survey. Mapping of the areas credited to C. P. Thornton, R. S. Young and W. T. Harnsberger, R. M. Allen, and the writer was done under the auspices of the Commonwealth of Virginia. Their maps and reports have been drawn upon freely in preparing this report.

Thanks are extended to Dr. C. M. Nevin, Cornell University, for advice and visits in the field. Many helpful discussions and geologic mapping advice were contributed by Dr. R. S. Edmundson, University of Virginia. Drs. R. S. Young, C. P. Thornton, and R. M. Allen made field visits and gave helpful suggestions. The aid and courtesies extended by many residents of the county are appreciated. Quarry operators and landowners kindly allowed the writer access to their properties. Thanks are extended to Mr. Larry Hayes, General Superintendent of the Bowers-Campbell zinc mine, for permission to examine the mine of Tri-State Zinc, Inc. at Timberville. The writer thanks the employees of the Division of Mineral Resources for cooperation, help, and advice on many matters, especially Dr. A. A. Pegau and field assistants Owen Bricker and Eugene Rader.

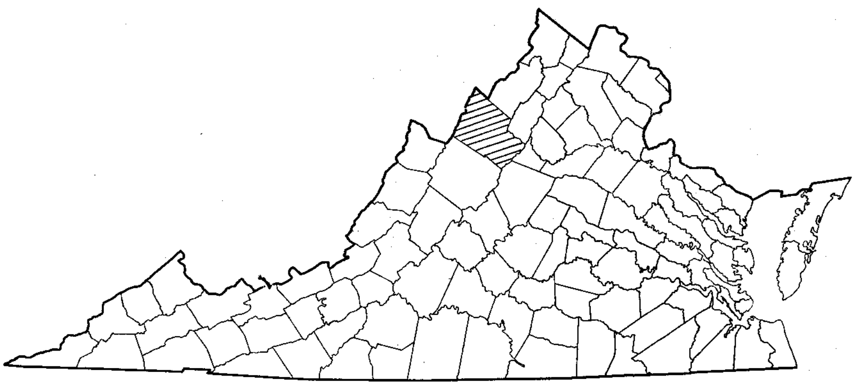


Figure 1.—Index map showing location of Rockingham County.

PREVIOUS WORK

Significant reports dealing with the geology in Rockingham County begin with W. B. Rogers' Annual Report on the Geology of the Virginias in 1835, published in 1884. The broad geological interpretations made by Rogers are accepted today. Several writers in the 1870's and 1880's described some of the mineral deposits in the Elkton area. Spencer (1897) published a map and a report on the geology of Massanutten Mountain. Significant contributions to the geology of the entire Valley of Virginia were made with the publication of Virginia Geological Survey Bulletins 42 and 52 in 1933 and 1940 respectively. These bulletins by Charles Butts contain a geologic map of the Valley of Virginia and discussions of the stratigraphy, structure, and paleontology of the whole Valley area.

Various geologists have written about the different aspects of the geology of parts of Rockingham County and many references have been made to its special features. The ores of manganese and iron were mentioned by Watson (1907) and Harder (1910). In 1919 a report by Stose and others dealing with the manganese ore deposits along the northwest foot of the Blue Ridge was published. It contained a geologic map and descriptions of individual deposits. Some mention of the cement resources was made by Bassler (1909). Clay deposits of the area were noted by Ries and Somers (1920) and ground-water resources were discussed by Cady (1936). Howell (1925) described the occurrences of coal in the county. The discovery of natural gas in the county was noted by Price (1942). A study of the limestones and dolomites of the area was made by Edmundson (1945). Stratigraphic studies in the county include those by Swartz (1929), and Cooper and Cooper (1946). The physiography of the general area has been mentioned by Stose (1919) and Wright (1925). Hammer and Heck (1941) discussed gravity features of the county.

The geology of the area around Elkton was described by King (1950), the geology in the Mt. Jackson quadrangle was reported on by Thornton (1953), the geology of the Harrisonburg quadrangle was discussed by Brent (1955), the geology of the Bergton area was presented in a short paper by Young and Harnsberger (1955), and sulfide mineralization of the county was described by Herbert and Young (1956). All of these last mentioned references were used freely in the preparation of this report.

GEOGRAPHY

Most of Rockingham County is in the Ridge and Valley province but the eastern part of the county extends into the Blue Ridge province (Fenneman, 1938, pp. 163-278). The lowest point in the county, about 900 feet above sea-level, is along the South Fork of Shenandoah River about 5 miles north of Elkton and just west of the town of Shenandoah, Page County. The highest point is 4,381 feet above sea-level atop Flagpole Knob, about 7 miles west of Rawley Springs. The maximum relief in the county is nearly 3,500 feet.

The most rugged topography is in the western part of the county in the mountains locally called "Alleghany," and in the eastern part, in the Blue Ridge. The gently rolling Shenandoah Valley occupies the 20-mile wide area between these mountains. Little North Mountain forms the northwestern border of the Valley throughout most of the county but where Little North Mountain is absent for about 5 miles north of the Augusta County line, the northwestern edge is marked by Narrow Back Mountain. West of Little North and Narrow Back mountains the rock formations are gently folded for the most part and streams have cut deep valleys. Most of this area is covered with dense forest and is relatively little inhabited. The southeastern edge of the Valley is sharply marked by the northwestern foot-hills of the Blue Ridge. Many of these foot-hills have the form of cuestas or hogbacks with dip slopes extending to the northwest. The lower western slopes of the Blue Ridge are underlain by Cambrian quartzites and are covered by forests. Precambrian or Cambrian igneous rocks commonly form the crest of the Blue Ridge.

The Shenandoah Valley is underlain principally by Cambrian and Ordovician limestones, dolomites, shales, and sandstones. Most of the people of the county live in this area. The topography is generally subdued but chert and sandstone hills and ridges are common. Mole Hill, an unusual feature, is an igneous body located about 4 miles west of Harrisonburg. The hills and ridges are wooded or used as orchard sites. The rolling lowlands usually are cleared and serve as grazing or farm lands. Shale areas commonly develop small steep-sided hills whereas limestone areas develop terranes that are dotted with sink-holes. Along the eastern part of the Valley are the northeast trending Massanutten ridges or ranges that are parts of a long synclinal complex. This topographic prominence extends from near Penn Laird and Montevideo to near Strasburg, Shenandoah County. These ridges are formed by the steeply inclined thick beds of Silurian sandstone and conglomerate. Massanutten Mountain, a major transportation barrier, is forested and has few inhabitants.

Surface drainage of the county is principally by three rivers, North River, North Fork of Shenandoah River and South Fork of Shenandoah River. The southwestern and southern parts are drained mainly by the North River which joins the Middle River at the Augusta County line about 1 mile west of Grottoes, and the latter joins the South River about 1.5 miles north of Grottoes to form the South Fork of Shenandoah River. Most of the streams in the northwestern and northern parts of the county empty into the North Fork of the Shenandoah. This river leaves the county, flowing in a northeasterly directio n, about 1.5 miles west of New Market, Shenandoah County. The largest river in the county, the South Fork of the Shenandoah, is in the eastern part of the county near the western slopes of the Blue Ridge. The course of the river is marked by a flood plain a mile or more wide and is bordered by gravel deposits up to 100 feet thick. The South Fork of Shenandoah River leaves the county about 5 miles north of Elkton, flowing toward the north.

The climate varies with the elevation in different parts of the county. Most of the people live in the Valley where the annual mean temperature is about 53° F., the January average temperature is 34° F., and the July average temperature is 73° F. Extremes of temperature are uncommon. Average annual precipitation is approximately 37 inches, mostly in the form of rain.

A climatic summary of 40 years of weather bureau records (1899-1938) of the Dale Enterprise weather station is in *Climate and Man* (Yearbook of Agriculture, 1941). Mean temperature and precipitation data from the Dale Enterprise station, expressed as averages for the period 1931-1955, are reproduced below (Rice, K. A., 1959).

	Temperature (°F)	*Precipitation (inches)*
January	35.6	2.25
February	36.2	1.84
March	43.0	3.01
April	52.6	2.44
May	62.3	3.99
June	70.1	3.93
July	73.5	4.59
August	71.7	4.39
September	66.1	3.04
October	56.0	2.69
November	44.4	2.28
December	35.8	2.35

The economy of the county in large measure is geared to agrarian enterprises. Most of the farms are fairly small, less than 50 acres, and present a prosperous aspect. Rockingham is the leading county in the Commonwealth in value of all farm products sold. Livestock farms are dominant and the principal products are poultry, cattle, sheep, and hogs. Other enterprises that contribute to the economy include mining, quarrying, lumbering, and manufacturing. Mining operations, while never a dominant factor in the county's economy, were fairly important some years ago. One significant mining development is the zinc mine of Tri-State Zinc, Inc., near Timberville, which began operations in April, 1957. Limestone quarries have been operated for many years and the industry is flourishing. Lumbering activities are not so extensive as formerly. A number of years ago the large hardwood trees were heavily cut and the new crop has not had time to obtain desirable size. Much of the forest area is within the boundaries of the George Washington National Forest and the Shenandoah National Park.

Most of the manufacturing plants in the county are small but industries are looking upon the area with increasing favor. A large plant of Merck and Co. is located near Elkton (Pl. 19A) and a plant of General

Electric Company is at Grottoes. Copious supplies of ground-water, especially in the eastern part of the county, make this area favorable for industrial development.

The county has a good network of roads. U. S. Highways 11 (north-south) and 33 (east-west) intersect at Harrisonburg near the center of the county. A branch of the new Inter-State Highway system is under construction parallel to U. S. Highway 11. U. S. Highway 340 (north-south) is parallel to and just east of the South Fork of Shenandoah River. The primary and secondary state roads are well maintained.

The Norfolk and Western, Chesapeake Western, and Southern Railways all provide freight service in the county. There are no present facilities to accommodate large commercial aircraft but an airport is under construction in Augusta County several miles south of the Rockingham County boundary.

STRATIGRAPHY

In Rockingham County bedrock ranges in age from Precambrian to Mississippian, with a maximum thickness of approximately 25,000 feet for the rocks of sedimentary origin. The oldest rocks, Precambrian, crop out in the Blue Ridge along the southeastern margin of the county. Overlying the Precambrian is a group of rocks of doubtful age, either Precambrian or Cambrian, which crops out at the crest and along the northwest flank of the Blue Ridge and is composed of rocks of igneous and sedimentary origin. Lower Cambrian shales, siltstones, sandstones, and quartzites are exposed along the northwest side of the Blue Ridge and rest on these older rocks.

The Shenandoah Valley is underlain principally by folded and faulted Cambrian and Ordovician dolomites, limestones, shales, and subordinate sandstones. About 5 miles northwest of the foot of the Blue Ridge is the Massanutten synclinal complex which has preserved Silurian and Devonian sandstones, shales, and limestones.

Little North Mountain consists mainly of steeply inclined Ordovician, Silurian, and Devonian sandstones, shales, and limestones. From Little North Mountain northwest to the West Virginia boundary is an area of chiefly Devonian and Mississippian sandstones and shales, but one anticline exposes Ordovician and Silurian sandstones, shales, and limestones. The folding to the northwest of Little North Mountain is commonly more gentle than that to the southeast of the mountain.

PRECAMBRIAN ROCKS

GENERAL STATEMENT:

Precambrian rocks in the county include igneous and metamorphic types. Their origin is in dispute but unquestionably the rocks have been subjected to many changes since consolidation. The rocks that are considered to be Precambrian were called "injection complex" by Jonas and Stose (1938, pp. 580-581), and by King (1950, p. 8), Brown (1958, p. 7) proposed the term Virginia Blue Ridge complex for these rocks and this terminology is used in this report. In the Elkton area, which includes part of Rockingham County, the Precambrian rocks are somewhat less metamorphosed and folded than in some other places and the relations between the rocks can be worked out with some assurance (King, 1950, p. 8). Here, according to King, the plutonic rocks are older than the

TABLE 1.—*Geologic formations of Rockingham County*

Age		Name	Map Symbol	Character	Thickness in Feet
Triassic		Intrusive igneous rocks	Tr	Dikes, sills, and plug of basic igneous rock.	
Mississippian		Pocono formation	Mp	Massive white to gray sandstone with some dark shale.	300+
Devonian	Upper	Hampshire formation	Dhs	Chiefly red sandstone, some flagstones, shales, and mudrock.	2000
Devonian	Upper	Chemung formation	Dch	Gray to greenish silty sandstone and brown to gray shale; fossiliferous.	2000
Devonian	Upper	Brallier shale	Db	Greenish to brown stiff micaceous shale and fine-grained thin-bedded greenish sandstone. Sparsely fossiliferous.	1200
Devonian	Middle	Millboro and Onondaga shales	Dmo	Fissile black shale, weathers light gray or pinkish. Needmore shale in Massanutten Mountain.	400-500
Devonian	Lower	Ridgeley (Oriskany) sandstone	Dri	Coarse-grained gray to white quartz sandstone with some calcareous cement; fossiliferous.	50-150
Devonian	Lower	Helderberg limestone (Helderberg group undivided)	Dhl	Gray limestone, crinoidal limestone, cherty limestone, some shale; fossiliferous.	100-400

Table 1.—Continued

Age	Name	Map Symbol	Character	Thickness in Feet
Silurian	Cayuga group	Scy	Chiefly finely-laminated gray limestone, probably Tonoloway limestone. Bloomsburg formation and overlying Tonoloway limestone in Massanutten Mountain.	220-600
Silurian	Clinton formation	Scl	Red sandstone, red and green shale. Keefer sandstone member resembles Clinch sandstone.	150-500
Silurian	Massanutten sandstone	Sm	Clinch and Clinton in Massanutten Mountain. White orthoquartzite, quartz pebble conglomerate commonly at base.	500-700
Silurian	Clinch sandstone (Tuscarora quartzite)	Sc	White to gray massive quartz sandstone with siliceous cement. Some quartz pebble conglomerate especially at base.	50-200
Ordovician, Upper	Juniata formation	Oj	Red sandstone and red shale.	250
Ordovician, Upper	Oswego sandstone	Oos	Thick-bedded greenish to bluish-gray dense sandstone, commonly iron-speckled. Thin shale partings.	300-600
Ordovician, Upper–Middle	Martinsburg shale	Omb	Shale, calcareous and silty in part. Fine-grained greenish sandstone containing *Orthorhynchula* at top.	1500-3000
Ordovician, Middle	Edinburg formation	Oe	Dense, dark-blue to black limestone, nodular weathering gray limestone; black shale commonly at base.	1500
Ordovician, Middle	Lincolnshire limestone and New Market limestone	Oln	Medium-grained, dark limestone with black chert.	50-150
			Dove-gray compact, pure limestone.	50-200
Ordovician, Lower	Beekmantown formation	Ob	Thick-bedded, gray, medium-grained dolomite, some blue limestone, much chert.	2000
Ordovician, Lower	Chepultepec limestone	Och	Blue and gray limestone, some dolomite. Some nodular black chert.	500

TABLE 1.—CONTINUED

Age			Name	Map Symbol	Character	Thickness in Feet
Cambrian	Upper		Conococheague limestone	€co	Thick-bedded bluish limestone, some dolomite, thin sandstone beds.	2500
Cambrian	Middle		Elbrook dolomite	€e	Thin- and thick-bedded dolomite, limestone, some shale.	2000
Cambrian	Lower		Rome (Waynesboro) formation	€r	Red and brown shale, calcareous shale, siltstone, some limestone.	1700
Cambrian	Lower		Shady (Tomstown) dolomite	€s	Dolomite, argillaceous dolomite, some limestone, some shale. Poorly exposed, commonly concealed by residual clay.	1000
Cambrian	Lower	Chilhowee group	Erwin (Antietam) quartzite	€eru	Upper member: brown sandstone and some quartzite.	400
				€erl	Lower member: white, thick-bedded quartzite, with *Scolithus* tubes.	400
Cambrian	Lower	Chilhowee group	Hampton (Harpers) formation	€h	Thin-bedded, dark-gray to greenish siltstone.	900
				€hs	Micaceous shale or phyllite at base.	
Cambrian	Lower	Chilhowee group	Weverton formation	€wu	Upper member: ferruginous quartzite, white arkosic quartzite, thin-bedded greenish siltstone.	700
				€wm	Middle member: micaceous shale or phyllite.	100
				€wl	Lower member: conglomerate and interbedded soft arkose.	100-700
Cambrian	Lower	Chilhowee group	Loudoun formation	€l	Spotted purple or gray slate, probably altered volcanic tuffs and breccias; some lava flows. Unconformable with Catoctin greenstone.	0-200
Cambrian or Pre-cambrian			Catoctin greenstone	€p€c	Altered basaltic lava, some amygdaloidal, some epidotized; interlayered tuffaceous sedimentary materials.	0-1000
Cambrian or Pre-cambrian			Swift Run formation	€p€s	Conglomerate, quartzite, slate. Unconformably overlies Virginia Blue Ridge complex.	0-100
Pre-cambrian			Virginia Blue Ridge complex	p€v	Granodiorite, gneiss, and other altered rocks.	

volcanic rocks and the Precambrian rocks can be divided into an older Precambrian series or injection complex, and a younger Precambrian series, the Swift Run formation and the Catoctin greenstone. Brown (1958, p. 8) assigned the Lynchburg gneiss, to which the Swift Run is partly equivalent, and Catoctin greenstone to the Late Precambrian. In this report, however, only the rocks below the Swift Run are designated Precambrian. The Swift Run and Catoctin are classed as Cambrian or Precambrian. The writer did not map that part of the county where these rocks are exposed, so the discussion of this area will follow previous publications.

VIRGINIA BLUE RIDGE COMPLEX

Name and distribution—The name Virginia Blue Ridge complex was suggested by Brown (1958, p. 7) for the rocks of the inner portion or core of the Blue Ridge structural province in Virginia. The rocks are a complex of schistose, gneissose, granitoid, and migmatitic rocks and are older than the Lynchburg and Swift Run formations. King (1950) used "injection complex" for this group of rocks following Jonas and Stose (1938). Also, this complex has been called "granitized complex" by Bloomer (1950) and "basement complex" by Bloomer and Werner (1955). The Geologic Map of Virginia (1928) designates these rocks as Lovingston granite gneiss, Marshall granite, albitite, and hypersthene granodiorite. According to King (1950) the main unit of this group present in the Elkton area appears to be hypersthene granodiorite, but variations occur and he made no detailed study of the group. The hypersthene granodiorite unit seems to be equivalent to the "Pedlar" formation proposed by Bloomer and Werner (1955, p. 582), and this usage was followed by Brown (1958). The Virginia Blue Ridge complex is exposed in a relatively small area in the extreme eastern part of Rockingham County on or near the top of the Blue Ridge.

Lithology—The character of the Virginia Blue Ridge complex (injection complex) in the Elkton area as described by King (1950, pp. 8-9) is: " . . . the rocks of the injection complex are coarse grained gneiss, composed of gently dipping, alternating light- and dark-colored bands a quarter of an inch to an inch thick, the different bands being composed of quartz and feldspar, and of ferromagnesian minerals. In detail, the texture is exceedingly irregular, with spots and segregations of the light and dark minerals, and with none of the minerals showing definite crystal faces. The ferromagnesian minerals are to some extent altered to light green epidote, and this mineral also invades the margins of the feldspar grains. The feldspar forms bodies up to an inch across, many with conspicuous cleavage faces, but generally broken and veined; it is commonly pink or rose-red. Quartz forms smaller grains, generally clear and vitreous, but in part tinted blue or violet.

"In irregular patches within the injection complex of the Elkton area, secondary alteration and introduction of epidote have proceeded so far that the rock is a unakite (Bradley, 1874, pp. 519-520).

"There appears to be no systematic distribution of the unakite, and it seems to be a local phase of the surrounding granodiorite."

Many writers have noted the occurrence of "blue quartz" in the "injection complex" in various places in the Blue Ridge. Blue quartz grains in the younger sedimentary formations are assumed to have been derived from weathering and erosion of the Precambrian "complex."

CAMBRIAN OR PRECAMBRIAN

There is a lack of general agreement as to where to place the boundary between the Precambrian and Cambrian rocks. After studies in the Elkton area, King (1950, p. 14) wrote: "The writer considers the Catoctin greenstone to be late pre-Cambrian in age. It lies unconformably beneath Lower Cambrian rocks, which are themselves about 3,000 feet beneath beds containing the earliest Lower Cambrian fossils." . . . "The writer concludes that, in the Elkton area, at least, the differences of the Catoctin and Swift Run formation from the overlying Chilhowee group are greater than the similarities, suggesting that the two units are parts of different geologic cycles, one of the pre-Cambrian and the other of Early Cambrian age."

With regard to the age of the Catoctin and related rocks, Brown (1958, p. 18) stated: "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."

Bloomer and Werner (1955, pp. 581-593) place the Swift Run formation and Catoctin formation in the Late Precambrian. Somewhat earlier Bloomer and Werner (1947, p. 106) said: "The relations and the lithologic similarity of the Oronoco, Catoctin, and Unicoi formations lead to the conclusion that these formations are a continuous stratigraphic series. If the Unicoi formation is Cambrian, then the Catoctin and Oronoco formations are also Cambrian." At another time, Bloomer (1950, p. 782) wrote: "The writer does not know whether the Lynchburg, Swift Run, Catoctin, and lower Chilhowee are Cambrian or late pre-Cambrian."

From the fore-going it appears that recently the tendency has been to place the Swift Run and Catoctin in the Late Precambrian, although there has been some controversy. Consequently, no definite age is assigned to the Swift Run and Catoctin. They are called Cambrian or Precambrian in this report in accordance with the policy of the Division of Mineral Resources.

SWIFT RUN FORMATION

Name and distribution—Sedimentary rocks below the Catoctin greenstone and unconformably overlying the "injection complex" were called "Swift Run" by Stose and Stose (1946, pp. 18-20). The type locality, on U. S. Highway 33, is three-fourths of a mile S. 58° E. of the Rockingham-Greene County line at Swift Run Gap. The name "Swift Run" formation was used for rocks in the same stratigraphic position by King (1950) who found that in the Elkton area it (Swift Run) is a nearly continuous bed that underlies the Catoctin greenstone. In Rockingham County the Swift Run formation crops out well up on the west side of the Blue Ridge. A good exposure of Swift Run can be seen along the Skyline Drive near Mile Post 70 in Powell Gap (R. M. Allen, personal communication).

Lithology and thickness—The Swift Run formation has a variable lithology. The description by King (1950, p. 10) is as follows: "Its most conspicuous element is vitreous, well-bedded, arkosic quartzite, of gray, pink, or greenish color, composed of quartz, pink and white feldspar and ferromagnesian minerals. Much epidote is present in the matrix. In most outcrops the quartz grains are colorless and vitreous, but at a few localities blue quartz has been noted. Some conglomerate layers are present, and some beds of crumbly, poorly cemented arkose. Interbedded with the quartzite in places are red and gray slate, and green, blebby pyroclastic rocks."

Where greenstone of Catoctin type is interlayered with the Swift Run, the contact is taken at the base of the lowest massive greenstone. Commonly the Swift Run is rather thin but considerable variations in thickness occur in short distances. In places it is 100 or more feet thick but a range of 10 feet to 50 feet is more common. Where the Swift Run is absent the Virginia Blue Ridge complex is directly overlain by Catoctin greenstone.

CATOCTIN GREENSTONE

Name and distribution—Catoctin greenstone was named "Catoctin schist" by Keith (1894a, pp. 306-309) from Catoctin Mountain, Maryland. The unit extends from the Maryland border in a southwesterly direction through the central part of Virginia. There are two main belts of outcrop, one at or near the summit of the Blue Ridge, and the other in the Piedmont province to the east. Outcrops in Rockingham County extend from the crest of the Blue Ridge down to the lower western slopes. A good exposure of Catoctin is along U. S. Highway 33 about ¾ mile west of the Skyline Drive at Swift Run Gap.

Lithology and thickness—The Catoctin, which commonly overlies the Swift Run with apparently conformable contact, consists principally of altered basic lava flows. The rock is commonly fine-grained and massive and may be dark-green, bluish, purplish, or gray in color. In some localities amygdules of quartz, epidote, feldspar, zeolite, or other minerals are present. Epidote occurs in many exposures of the Catoctin and may replace ledges of the original rock to form epidosite. King (1950, p. 13) noted that pyroclastic rocks make up a considerable part of the Catoctin. He considered the pryoclastics to be sedimentary rocks derived from the same sources as the lavas. Flows, slaty pyroclastics, and flow breccias within the Catoctin show a pervasive southeast dipping cleavage (R. M. Allen, personal communication). In a study of the Luray area (Reed, 1955, p. 879) stated: "Sedimentary members are common but not extensive, and none of these interbeds is more than 40 feet thick, although the basal sedimentary layer locally reaches 150 feet . . ." and that "Sedminentary members of the formation are mostly arkoses, graywackes, and conglomerates derived from the under-lying granitic rocks and sericite phyllites which may be derived from volcanic ash layers." In thin section, Reed (1955, p. 879) found the following minerals: albite, chlorite, epidote, actinolite, and sphene, with minor amounts of pyroxene, magnetite, hematite, and ilmenite. The Catoctin in this area is less metamorphosed than it is in the vicinity of Lynchburg but otherwise is generally similar (Brown, 1958, p. 25).

Southeast of Elkton the Catoctin is probably 1,000 feet thick but it thins to the northeast and is absent northeast of Shenandoah, Page County. King (1950, p. 13) suggested that considerable variations in thickness of the Catoctin may be expected as a result of overlap at the base and erosion at the top of the formation.

CAMBRIAN SYSTEM

GENERAL STATEMENT

Safford (1856, pp. 152-153; 1869, pp. 198-203) proposed the name "Chilhowee sandstone" from exposures on Chilhowee Mountain, Blount County, Tennessee. Butts (1940, p. 26) used "Chilhowee group," extending this term into Virginia from Tennessee where it was previously used. This group is called "basal quartzites" on the Geologic Map of the Appalachian Valley in Virginia (1933). King (1950, p. 15) wrote: "The name (Chilhowee group) is applied to clastic rocks in Tennessee and Virginia that lie unconformably on pre-Cambrian rocks and are overlain by the Shady or Tomstown dolomite."

The Chilhowee commonly is divided into four formations, Loudoun formation, Weverton sandstone, Hampton-Harpers shale, and Erwin-Antietam sandstone. In Tennessee "Unicoi formation" is used for the Loudoun and Weverton taken together, but "Unicoi" will not be used here. Hampton and Erwin are the names that have been applied to the two upper formations of the Chilhowee group in areas south of Roanoke and Harpers and Antietam for these formations north of Roanoke. In an attempt to establish uniform terminology, the terms Hampton and Erwin are used in this report.

LOUDOUN FORMATION

Name and distribution—Keith (1894, pp. 324-329) named the Loudoun formation from outcrops in Loudoun County, Virginia. No definite type locality was described but the name has been applied to the beds (Early Cambrian?) that appear to be between the Catoctin and Weverton.

In Rockingham County the Loudoun is exposed on the west slopes of the Blue Ridge, between the Catoctin on the east and the Weverton on the west. There is a good exposure of Loudoun along the Skyline Drive at the head of Madison Run near Browns Gap, and another outcrop in a small anticline which crosses Madison Run about one and three-quarters miles west of Browns Gap (R. M. Allen, presonal communication). King (1950 p. 16) has suggested that doubt exists as to whether the Loudoun formation is a valid unit. Further study is necessary to establish the true relationships.

Lithology and thickness—The Loudoun as described by King (1950, p. 16) is: ". . . dominantly a slaty unit, probably largely of pryoclastic origin. Most of the slate is dull purple or dull red, generally with a strong cleavage that forms lustrous, micaceous surfaces. The purple or red slate commonly contains numerous round or oval, light green spots that range from an eighth of an inch to a quarter of an inch in diameter." In places the slate is interbedded with sericitic schist and with green or gray slate. Reed did not use the term "Loudoun formation" but called the rock in that stratigraphic position "purple volcanic slate" (Reed, 1955, p. 891). In addition to megascopic description, he included a thin section description and two chemical analyses of the rock (Reed, 1955, pp. 892-893). With regard to origin, Reed (1955, p. 893) wrote: "Field relationships and petrography suggest that the slate is a metamorphosed saprolite developed at the top of the Catoctin formation prior to deposition of the overlying sediments." The thickness of the Loudoun in the Elkton area is given by King (1950, p. 17) as approximately 100 feet. Thickenings and thinnings of the formation occur but are relatively uncommon. In places the formation appears to be absent.

WEVERTON FORMATION

Name and distribution—Keith (1894, pp. 329-333) named the Weverton sandstone for exposures on South Mountain near Weverton, Maryland. It was called Weverton formation by King (1950, p. 17) because it contains a variety of other clastic rocks in addition to sandstone.

In Rockingham County the unit crops out on the northwest slopes of the Blue Ridge. Outcrops are fairly common and some good sections are exposed along creek banks, as in the valley of Swift Run near U. S. Highway 33.

Lithology and thickness—The formation was divided into lower, middle, and upper members by King (1950, pp. 18-19). At the head of Gap Run, Rockingham County, the lower member consists of about 700 feet of greenish fine-grained sandstone, siltstone, and silty slate, and a few beds of coarse materials. In the vicinity of Black Rock, to the southwest, this member is conglomeratic and is thicker than it is to the northeast. The middle member is about 100 feet thick and is largely argillaceous shale with some beds of arkosic siltstone and fine sandstone. When fresh the rock is greenish and has a marked cleavage with shiny micaceous surfaces. The upper member is about 700 feet thick and is mainly interbedded sandstone, siltstone, and quartzite. Indistinct traces of *Scolithus* were noted by King (1950, p. 19) in the light-colored quartzite of this member. The top of the Weverton commonly is marked by 1 foot to 5 feet of ferruginous quartzite.

HAMPTON (HARPERS) FORMATION

Name and distribution—Keith (1893, p. 68) named the "Harpers shale" from outcrops near Harpers Ferry, West Virginia. The Hampton shale (Campbell, 1899) was named from Hampton, Carter County, Tennessee. The term Hampton will be used in this report. Outcrops in the county occur on the west slopes of the Blue Ridge and one of the best exposures is along Hawksbill Creek on the northwest flank of the Hanse Mountain anticline.

Character and thickness—A green fissile, argillaceous shale, up to 200 feet thick, which is commonly at the bottom of the formation, is mapped as a separate unit by King (1950) and by R. M. Allen. The main body of the Hampton consists principally of thin beds of dark-greenish siltstone and fine-grained sandstone. These beds commonly weather to various shades of brown marked by rusty colored spots. In places thick quartzite beds or lenses occur at various horizons in the formation.

Accurate thickness measurements are difficult to make because of the poor exposures and structural complications. Estimates of thickness range from 800 feet to 2,750 feet. King (1950, p. 20) found that the formation has a nearly constant thickness of about 900 feet in the Elkton area.

Fossils and age—Some of the quartzite beds contain *Scolithus*, similar to those in overlying Erwin quartzite. Other than this, no recognizable fossils have been found in the formation. A probable Cambrian age is indicated for the Hampton by its position directly below beds containing *Olenellus* (Butts, 1940, p. 38).

ERWIN (ANTIETAM) QUARTZITE

Name and distribution—The Antietam sandstone was named by Keith, (1893, p. 68) from Antietam Creek in Maryland. The Erwin quartzite was named from Erwin, Unicoi County, Tennessee (Keith, 1903, p. 5) and this name is used in this report. The formation crops out along the west slopes of the Blue Ridge and makes a number of high peaks. In places, high ridges are formed with dip slopes extending to the west down to the Shenandoah Valley. These cuesta or hogback type ridges are cut by streams that empty into the South Fork of the Shenandoah River. The sides of the ridges have extensive fields of angular quartzite blocks that have fallen from higher elevations.

Character and thickness—The formation consists almost entirely of thick beds of clean, well-sorted grains of white quartz sand which are cemented with silica. King (1950, pp. 22-23) divided the formation into a lower member and an upper member of about equal thickness. The lower member, as seen in cliffs, is principally massive beds of quartzite. These beds commonly contain *Scolithus* tubes, which begin on bedding planes and extend downward perpendicular to bedding for distances of more than 3 feet in some cases (Pls. 4A, 4B). The beds of the upper member are generally thinner, less persistent, and weather more easily than those of the lower member. *Scolithus* tubes are less common in the upper member.

One thin section of quartzite, cut perpendicularly to several *Scolithus* tubes, was examined. The section consists almost entirely of interlocking quartz grains (Pl. 5A). The other minerals present are: sericite, hornblende, epidote, ilmenite, leucoxene, apatite, and questionable clinozoisite and spinel. The quartz grains generally have one long dimension and show good alignment. All the grains show strain shadows and the boundaries commonly have sutured contacts. No oriented overgrowths were noted on any of the grains. The largest grain measured was 1.2 mm by 1.2 mm, and the smallest 0.08 mm in diameter. The average grain is about 0.25 mm in diameter. Tiny shreds of sericite occur locally as concentrations. The other accessories are generally less than 0.3 mm in diameter and are present only in small quantities.

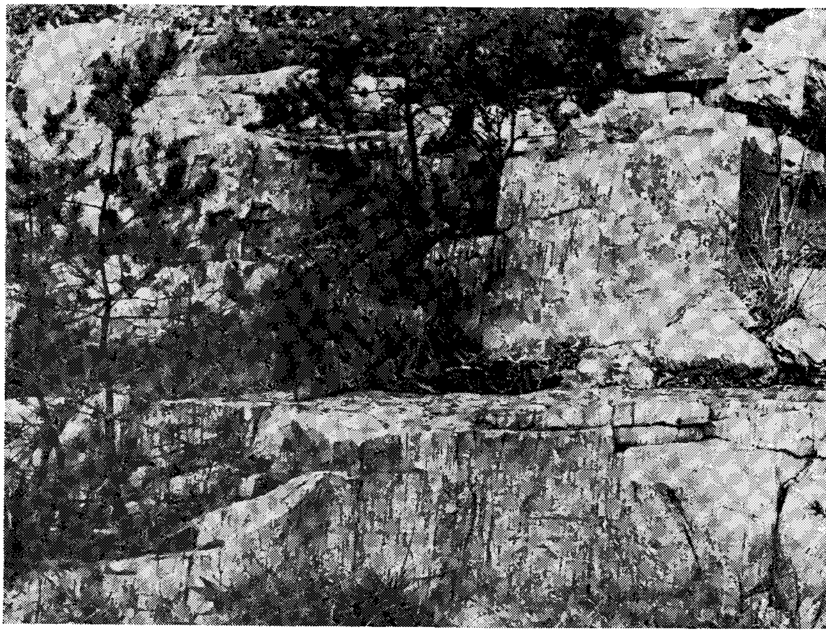
In Rockingham County the formation seems to have a thickness of between 800 feet and 1000 feet. In the Elkton area the Erwin (Antietam) quartzite has a rather uniform thickness of about 800 feet (King, 1950, p. 21). The thickness of the formation is about 1500 feet west of Whites Gap, Rockbridge County (Butts, 1940, p. 40).

Fossils and age—An early Cambrian age is indicated by species of *Olenellus*, *Hyolithes*, and *Obolella* which have been collected from the formation (Resser, 1938, p. 5; Butts, 1940, p. 40). No fossils other than *Scolithus* have been found in the Erwin (Antietam) in Rockingham County and King (1950) reported no others in the Elkton area.

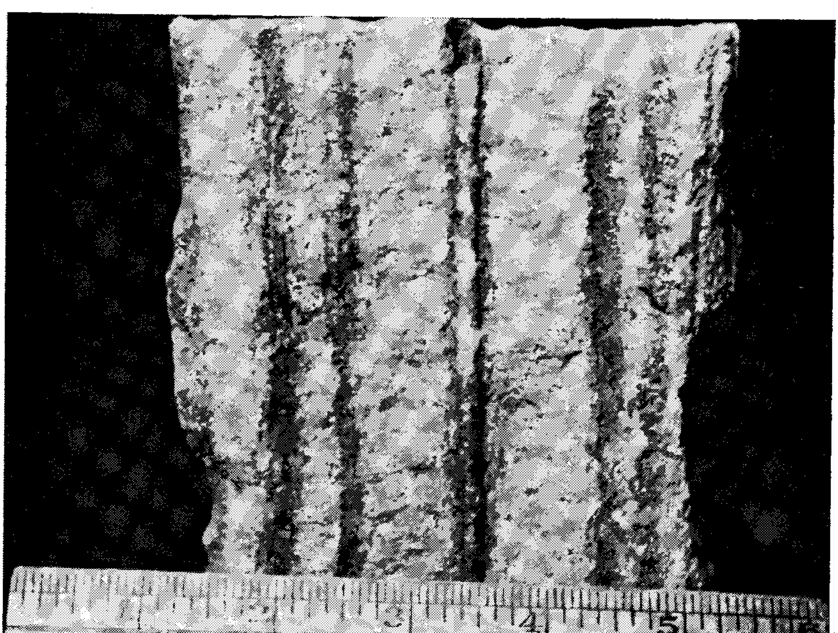
SHADY (TOMSTOWN) DOLOMITE

Name and distribution—The Tomstown limestone was named by Stose (1906, p. 208) from Tomstown, Pennsylvania. Previously, Keith (1903, p. 5) had named the Shady limestone, which is essentially the same as the Tomstown, from Shady Valley, Johnson County, Tennessee (Butts, 1940, p. 40). In Virginia the formation is mainly dolomite and the term Tomstown dolomite has customarily been used north of Roanoke. However, the name Shady has priority, and following Edmundson (1958, p. 13) is used here for occurrences of the formation north of Roanoke. Outcrop of the Shady dolomite in Virginia is restricted to one

Plate 4

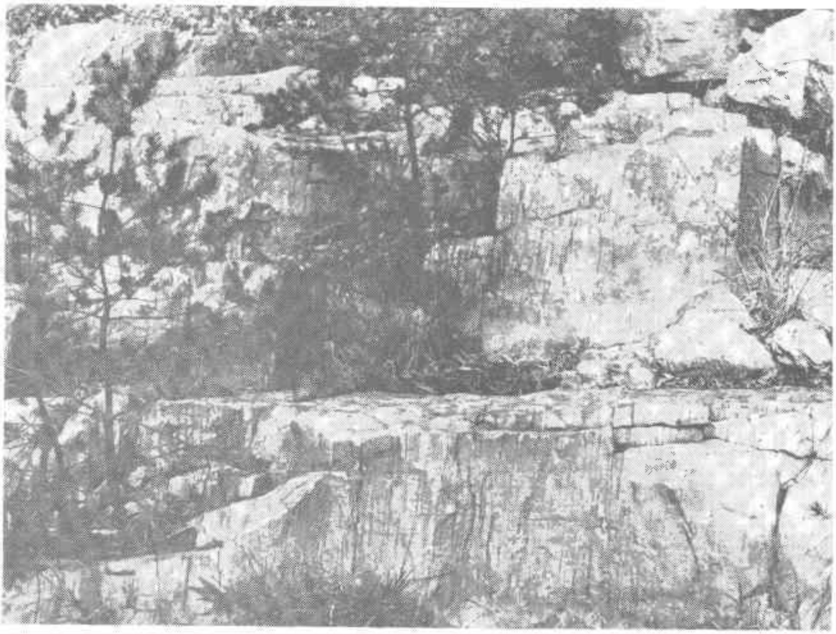


A. *Scolithus* tubes, vertical markings, in Erwin quartzite. About 2.5 miles east of Grottoes.

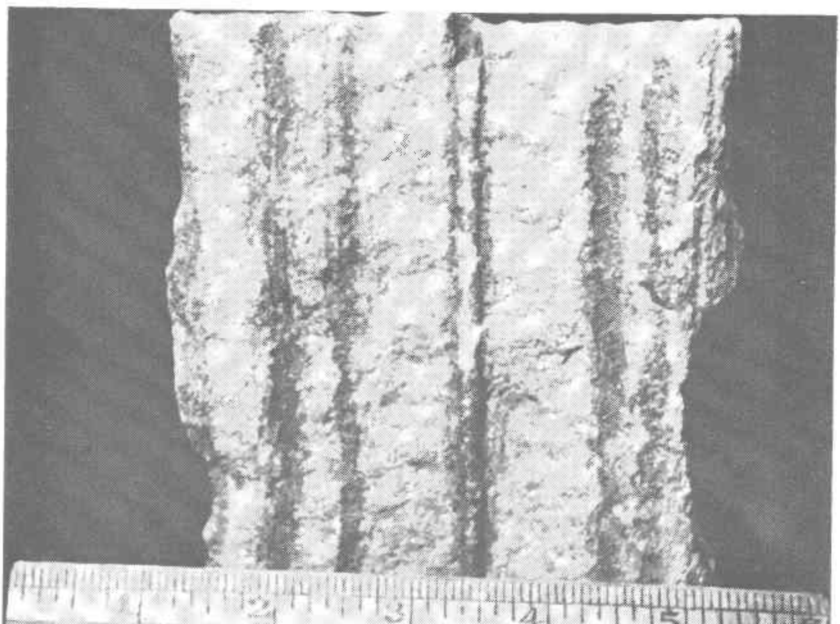


B. *Scolithus* tubes in Erwin quartzite.

Plate 4

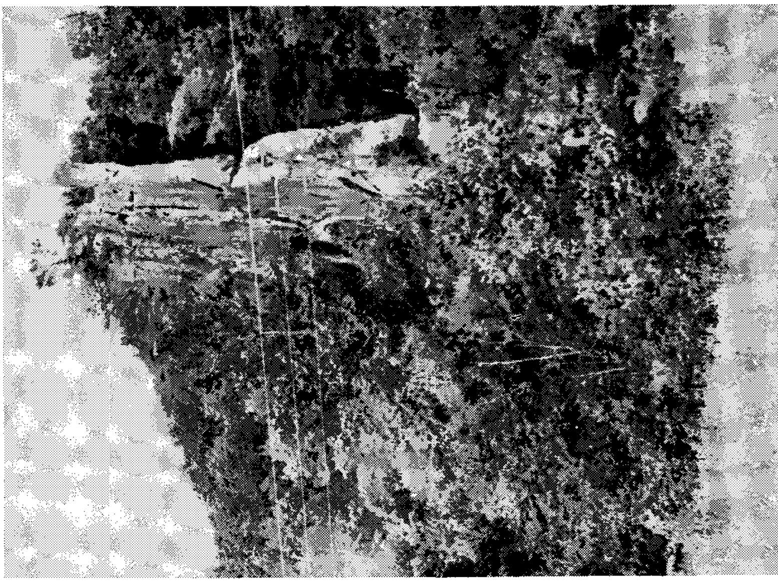


A. *Scolithus* tubes, vertical markings, in Erwin quartzite. About 2.5 miles east of Grottoes.

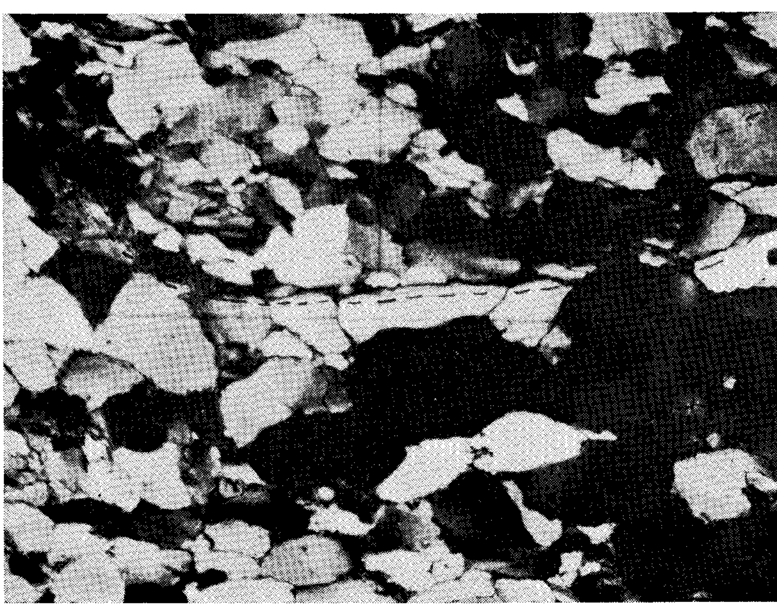


B. *Scolithus* tubes in Erwin quartzite.

Plate 5

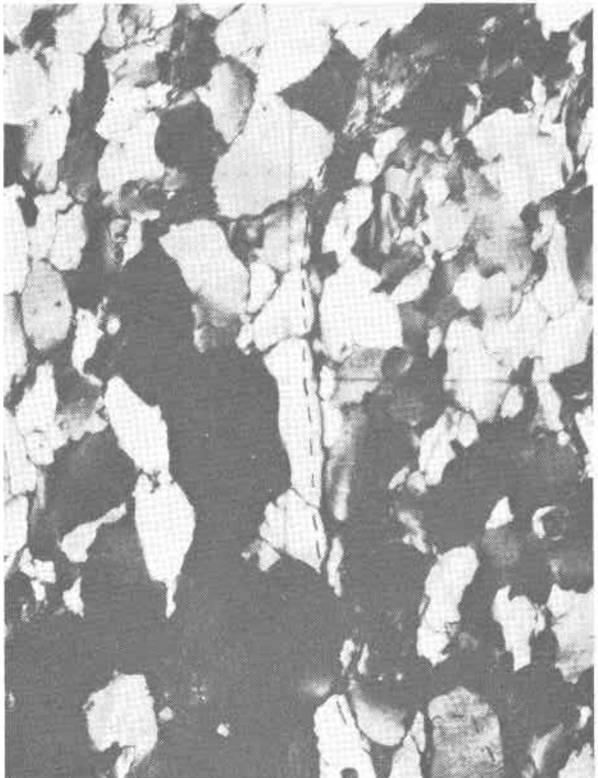


B. Chimney Rock. Vertical Ridgeley (Oriskany) sandstone at west end of Brocks Gap in Little North Mountain.



A. Photomicrograph of Erwin quartzite. Note *Scolithus* tube partially enclosed by dashed line, to right of vertical cross-hair. Crossed nicols. x40.

Plate 5



A. Photomicrograph of Erwin quartzite. Note *Scolithus* tube partially enclosed by dashed line, to right of vertical cross-hair. Crossed nicols. x40.

B. Chimney Rock. Vertical Ridgeley (Oriskany) sandstone at west end of Brocks Gap in Little North Mountain.

belt along the northwest foot of the Blue Ridge (Butts, 1940, p. 52—). The formation is poorly exposed in Rockingham County; it is commonly deeply weathered and covered by a thick mantle of residual clay. In places the Shady is hidden by a fairly thick deposit of gravel that has washed down from the nearby Blue Ridge.

Character and thickness—The Shady consists predominately of beds of dolomite with some limestone layers; however, the character of the formation varies considerably. Beds of thick-bedded blue limestone, fine-grained blue limestone, fine-grained blue dolomite, light gray compact dolomite, and white crystalline dolomite, together with beds of still different character all occur in a single section. Descriptions of the residuum of the Shady (Tomstown) and descriptions of the formation from subsurface information were given by King (1950, pp. 26-30) for the Elkton area.

As a result of cover by talus and gravel, faulting, and deep weathering, thickness determinations are difficult to obtain. In the Elkton area a thickness of about 1000 feet was found (King, 1950, p. 25) which agrees fairly well with the estimate of 1000 feet to 1500 feet by Edmundson (1945, p. 180) for the Tomstown (Shady) in Clarke County. A thickness of about 1000 feet is assumed for the Shady in Rockingham County.

Fossils and age—The Shady is generally described as being sparingly fossiliferous. In addition to *Archaeocyathus* reefs, species of brachiopods, gastropods, and trilobites have been found at certain places and a list of these fossils is in Virginia Geological Survey Bulletin 52. In the Elkton area King (1950, p. 25) found only a reefy mass that is described as possibly a *Cryptozoon*. An Early Cambrian age for the formation is indicated by the fossil content.

ROME (WAYNESBORO) FORMATION

Name and distribution—Stose (1906, p. 209) named the Waynesboro formation from Waynesboro, Pennsylvania. The name "Rome" was used by Hayes (1891) for the same unit exposed at Rome, Georgia (Butts, 1940, p. 56). Since the name Rome is in established usage and was used before introduction of "Waynesboro," it seems desirable to use the name Rome for the formation in Virginia. In Rockingham County the Rome (Waynesboro) occurs as a single belt in the Valley proper. It is east of the South Fork of the Shenandoah River except where crossed by eastward extending bends or meanders of the river. Some outcrops occur although the formation is mostly covered by residual material from weathering and by alluvium. One good accessible outcrop is along the Norfolk and Western Railway tracks at a bend in the South Fork of the Shenandoah River about 3 miles southwest of Island Ford.

Character and thickness—The Rome formation consists of many different types of rock which vary in proportion and distribution from place to place. Beds of red shale, green shale, sandstone, dolomite, and limestone all occur at various horizons in the formation but shale is generally dominant. The shales, especially the red shales, are a good means of identifying the formation because no significant beds of similar shales underlie or overlie the formation for several thousand feet. Thick beds of coarsely crystalline dolomite, which strongly resemble the Shady dolomite, occur in places. Folding, faulting, and cover make accurate thickness determinations difficult. Along Crooked Run, approximately 1 ½ miles north and east of Shenandoah, Page County, King (1950, p. 31) measured 1685 feet of the Rome (Waynesboro) in the nearly vertical beds exposed there. The thickness of the Rome in Rockingham County is probably close to this figure.

Fossils and age—The Rome (Waynesboro) formation in Virginia contains few fossils and the known fossil localities are in the southwestern part of the state (Butts, 1940, p. 63). Some of the fossils suggest an Early Cambrian age for the formation and others indicate a Middle Cambrian age. The Rome formation of Tennessee, which resembles the Rome (Waynesboro) of Virginia in character and stratigraphic position, is entirely Early Cambrian (King, 1950, p. 31).

ELBROOK DOLOMITE

Name and distribution—The Elbrook limestone, named by Stose (1906, p. 209) from Elbrook, Franklin County, Pennsylvania, is called Elbrook dolomite in Virginia. The Elbrook has three belts of outcrop in Rockingham County; two with faulted relations, and one complete section. The easternmost belt extends from Grottoes, northeast to Elkton where it turns almost due north. A few good outcrops occur near Elkton and at locations a mile or two southwest of Island Ford, but much of this belt is covered by stream deposited sand and gravel. West of this belt the Staunton fault brings up a partial section of Elbrook and still farther west the formation occurs on the east side of the Little North Mountain fault.

Character and thickness—The Elbrook consists principally of dolomite but has beds of blue limestone and some shale in places. In parts of Pennsylvania and Maryland, Wilson (1952, p. 304) found that: "The Conococheague-type limestone has been noted from the very top of the

Elbrook to as low as 800 feet below the base of the Conococheague." The dolomite is generally light gray and fine-grained and may be either thin- or thick-bedded. Argillaceous beds commonly weather to a yellow crumbly shale (Pl. 10B). A distinctive feature of the formation is the punky yellow coating that covers some surfaces of the weathered dolomite. Thin siliceous bands commonly stand out in relief on weathered surfaces of some of the limestone beds. In the Elkton area the formation has an estimated thickness of about 3000 feet (King, 1950, p. 32). To the southwest, near Buena Vista, a thickness of about 2200 feet for the Elbrook is recorded (Edmundson, 1958, p. 19). No thickness measurements of the Elbrook could be made in Rockingham County because of faulting, folding, and extensive alluvial cover.

Fossils and correlation—The only identifiable fossil seen in the Elbrook in Rockingham County was *Cryptozoon*. *Glossopleura*, which indicates a Middle Cambrian age, has been found in the formation at other localities. In southwestern Virginia and Tennessee the equivalents of the Elbrook are the Rutledge limestone, Rogersville shale, Maryville limestone, and the Nolichucky shale.

CONOCOCHEAGUE LIMESTONE

Name and distribution—Stose (1908, p. 701) named the Conococheague limestone from Conococheague Creek in Franklin County, Pennsylvania. Three main northeast trending belts of Conococheague cross Rockingham County. One extends toward the northeast from Grottoes and passes just west of Elkton where it turns almost due north. Another belt extends northeast from the Augusta County line through Keezletown and is cut out by the Staunton fault near Union Chapel. The third crosses the county to the east of and roughly parallel to the Little North Mountain fault. In a southwest plunging anticline east of Broadway and Timberville is exposed in Rockingham County for about 7 or 8 miles, a band of Conococheague about a mile wide.

Character and thickness—The Conococheague consists principally of thick-bedded bluish limestone. Characteristically, the weathered surfaces of the formation have projecting wavy bands of siliceous material. Beds of medium-grained sandstone, the diagnostic feature of the Conococheague, occur throughout the formation (Pl. 6A). Some of the sandstones pinch out in a short distance but others extend at least 20 miles. Although variable, the sandstones may have an aggregate thickness of 30 feet or more. Some massive sandstone beds occur just east of the Little North Mountain fault. The upper part of the formation may be determined by the presence of siliceous oolites that occur either in chert or in limestone beds (Pl. 6B). Considerable amounts of light gray dolomite occur at intervals and lenticular beds of intraformational conglomerate are fairly common in parts of the formation. Along North River about 0.5 mile southeast of Spring Creek is an area of dark, granular dolomite which is mapped as Conococheague. This dolomite has many cavities lined with carbonate crystals and is similar to the lithology that occurs near the base of the Beekmantown east of Mt. Clinton. It is possible that the dark dolomite near Spring Creek is Beekmantown (or Chepultepec) preserved in a syncline but there are not enough exposures to prove this and the dark dolomite beds were mapped as Conococheague.

Accurate thicknesses of the Conococheague are difficult to obtain in Rockingham County because of faulting, folding, and discontinuous exposures. The thickness of the formation throughout Virginia is about 2000 feet (Butts, 1940, p. 89). More recent estimates in areas near Rockingham County give the thickness as about 2500 feet (Edmundson, 1945; Young, 1954). The thickness of the Conococheague southeast of Natural Bridge is approximately 2100 feet (Edmundson, 1958, p. 19). Judging from the general structure and width of outcrop, the thickness of the Conococheague limestone in Rockingham County is about 2500 feet.

Fossils and correlation—The Conococheague is generally described as sparingly fossiliferous. Masses of material that have the appearance of broken fragments of fossils occur in the formation in Rockingham County but none have been identified. *Cryptozoon* reefs occur in the Conococheague in Rockingham County and elsewhere. Other than reefs of *Cryptozoön*, which are locally well-developed, the known fossils of the formation consist principally of trilobites, gastropods, and brachiopods. Resser (1938, p. 20) correlated the Conococheague with a part of the Warrior formation and all of the Gatesburg formation of Pennsylvania. The Copper Ridge dolomite of southwest Virginia is correlated with the Conococheague (Butts, 1940, p. 90).

ORDOVICIAN SYSTEM

CHEPULTEPEC LIMESTONE

Name and distribution—The Chepultepec limestone was named by Ulrich (1911, p. 638) from exposures near Chepultepec, Blount County, Alabama. There are several thin belts of Chepultepec in Rockingham County; all are within the Shenandoah Valley southeast of Little North Mountain and its trend. The formation generally is found in topographically low areas and good exposures are not common. The valleys

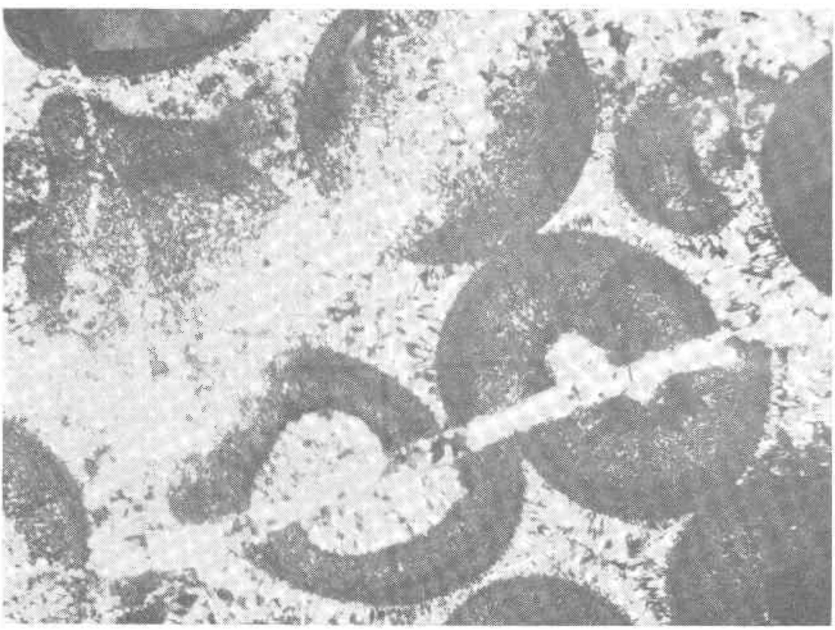
Plate 6

A. Sandstone beds in the Conococheague limestone about 3 miles south of Mt. Crawford.

B. Photomicrograph of micro-fault cutting oolites in Conococheague limestone. Crossed nicols. x40.

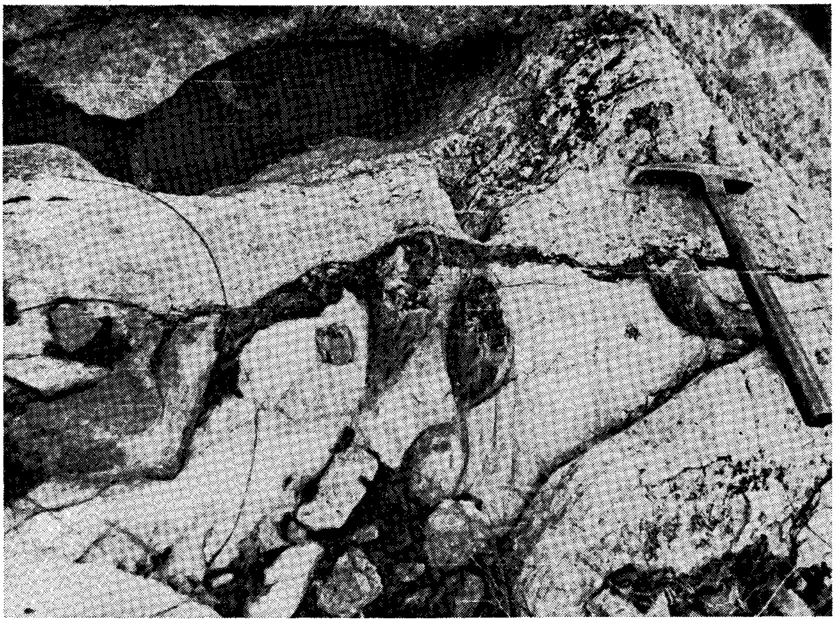
Plate 6

A. Sandstone beds in the Conococheague limestone about 3 miles south of Mt. Crawford.

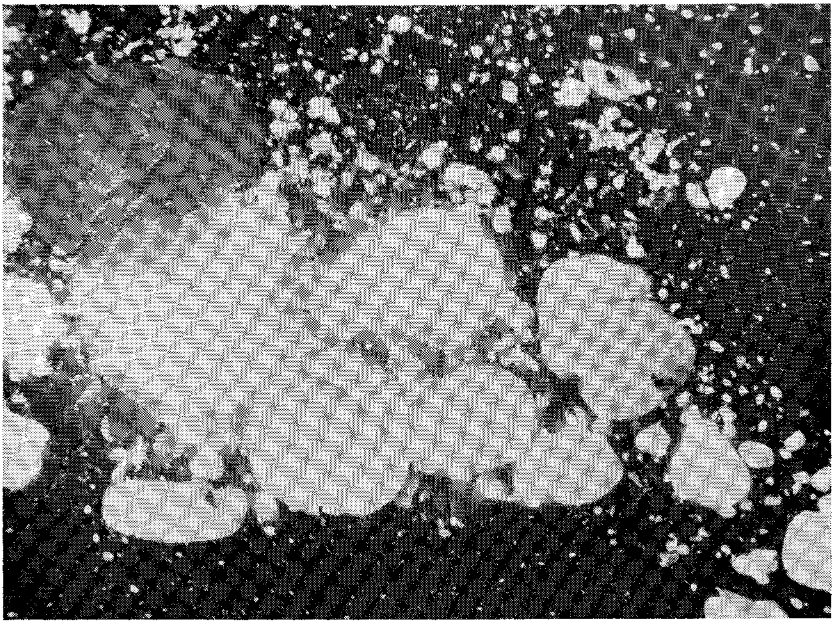


B. Photomicrograph of micro-fault cutting oolites in Conococheague limestone. Crossed nicols. x40.

Plate 7

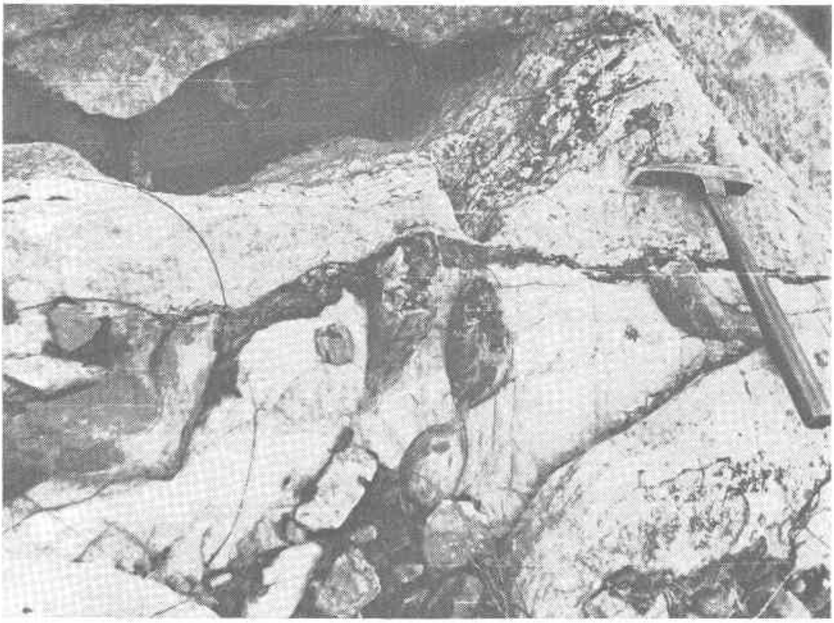


A. Nodular chert in Chepultepec limestone near Mt. Clinton.

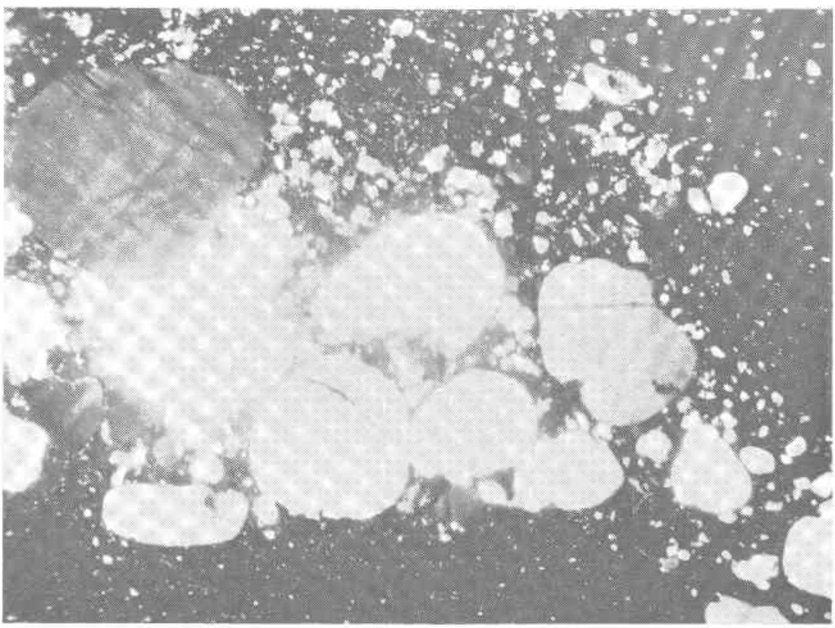


B. Photomicrograph of quartz sand grains in Beekmantown dolomite near Harrisonburg. Crossed nicols. x40.

Plate 7



A. Nodular chert in Chepultepec limestone near Mt. Clinton.



B. Photomicrograph of quartz sand grains in Beekmantown dolomite near Harrisonburg. Crossed nicols. x40.

occupied by Chepultepec commonly are bounded by ridges of Conococheague sandstone on one side and by lines of Beekmantown chert hills on the other.

Character and thickness—The Chepultepec consists of blue to gray dense limestone with some dolomite layers. Rows of distinctive projecting black chert nodules are present at some outcrops (Pl. 7A). The blue limestone is similar to that of the underlying Conococheague, but the Chepultepec generally has fewer of the silty laminations that are characteristic of the Conococheague. In the eastern part of the county the Chepultepec is principally dense blue limestone with scattered chert nodules. This character is maintained throughout most areas of exposures along the strike. The western belt of Chepultepec has considerable dolomite in some areas and the relative amount of dolomite seems to increase toward the southwest. Dense blue limestone with black chert nodules is common in the northeastern part of the western belt but this lithology is rarely exposed toward the southwest.

A partial section, 266 feet thick, was measured about a mile north of Trissel Church. The base and top of the formation were covered so the true thickness could not be determined. Fairly reliable estimates indicate a maximum thickness of approximately 500 feet for the formation in Rockingham County; a similar thickness has been measured in Frederick and Shenandoah counties (Butts, 1940, p. 100).

Fossils and correlation—The characteristic fauna of the Chepultepec is composed of cephalopods and gastropods. Species of *Dakeoceras* and *Levisoceras* are dominant among the cephalopods and *Helicotoma* among the gastropods. Solution of the limestone in dilute hydrochloric acid commonly will yield many small silicified fossils in the residue. The upper portion of the Chepultepec is correlated with the Stonehenge limestone of central Pennsylvania and the Tribes Hill limestone of New York (Butts, 1940, p. 101).

BEEKMANTOWN FORMATION

Name and distribution—The name Beekmantown was selected by Clarke and Schuchert (1899, pp. 874-878) from a New York locality to replace an older descriptive name. Here, the term Beekmantown formation includes the dolomites and limestones lying between the distinctive cephalopod-bearing limestones of the Chepultepec below and the high-calcium sub-lithographic limestones of the New Market above. The Beekmantown has several extensive northeast trending belts of outcrop, mainly in the central parts of Rockingham County.

Character and thickness—The Beekmantown consists principally of thick-bedded, gray, fine-grained to medium-grained dolomite with some beds of blue limestone. The character of the dolomite and the thickness and location of the limestones are subject to some variation. In places there is a sugary-textured intraformational breccia, of angular fragments of light colored dolomite in a dark dolomite matrix, near the base of the formation. A zone of doubly terminated quartz crystals is present just above the breccia zone near Mt. Clinton. Chert horizons, which seem to be lenticular, occur at various places in the formation and cause the formation of rounded hills that are conspicuously higher than the immediately surrounding area. In the eastern belts there is considerable limestone in the Beekmantown, particularly in the upper part, which is well displayed in the quarries of the Elkton Lime and Stone Company, about 3 miles northwest of Elkton. In the western part of the county the formation is dominantly dolomite with relatively few scattered limestone layers. Locally, the residual soil of the Beekmantown is colored red and is strewn with nodules and cobbles of limonite, and quartz sand grains occur in the formation near Harrisonburg (Pl. 7B). Upon weathering the Beekmantown commonly yields abundant porous chert, some of which is highly fossiliferous. Beds of gray sub-lithographic limestone, similar to the dense gray limestone of the overlying formation, occur interbedded with dolomite near the top of the formation. The character of the Beekmantown in the eastern part of the county is shown by Geologic Section 3, about 3 miles northwest of Elkton, and the character in the western part of the county by Geologic Section 2, about 1.5 miles east of Singers Glen. There is no area of continuous outcrop in the county where a complete section can be measured. Based on average dip and width of outcrop, the formation has an estimated thickness of 1,900 feet to 2,500 feet. Butts (1940, p. 116) gave a thickness of about 2,500 feet for the Beekmantown west of Strasburg, Shenandoah County. A thickness of between 1,500 feet and 2,000 feet was estimated by Edmundson (1945, p. 118) for the Beekmantown in central Augusta County. A measured section northeast of Green Hill, east of Singers Glen, Rockingham County has a thickness of 1,922 feet, but the lower 700 feet (included in the total) was mostly covered (Geologic Section 2). The measured thickness is approximate because offsets had to be made and the dips are low and variable. The upper contact is distinct but the basal contact with the Chepultepec is only approximate.

Fossils and correlation—The Beekmantown is moderately fossiliferous and is divisible into two zones on a faunal basis. Well preserved fossils occur in limestone and in the chert of certain areas, but are fairly rare in dolomite. Species of *Lecanospira*, *Roubidouxia*, and *Hormotoma* characterize the lower zone. The upper zone is identified by the presence of species of *Ceratopia* and *Lophonema*. The lower (*Lecanospira*) zone is correlated with the Nittany dolomite of Pennsylvania and the upper (*Ceratopia*) zone with the Bellefonte of that area. Microfossils in the Beekmantown are shown by photomicrographs of bryozoans and other fossils, but little is known of their significance (Pls. 8A, 8B).

UNCONFORMITY

An unconformity (disconformity) at the top of the Beekmantown is indicated by variations in thickness of the overlying New Market and by conglomeratic beds at the base of the New Market at some localities. There are no indications that the New Market is absent, by reason of lack of deposition or erosion, at any place in the county.

Evidence from other areas for an unconformity at the top of the Beekmantown includes the observation by Butts (1940, p. 136) that the basal Mosheim (New Market) occupies a rather deep depression in the Beekmantown at a locality near Staunton. Additional indications of an unconformity at this horizon include the local absence of the New Market limestone, and the absence of typical Chazy (type Lenoir) fossils in beds above the Beekmantown except in a few localities where the typical Lenoir brachiopod, *Rostricellula pristina*, occurs below the "Mosheim" beds of the New Market limestone (Cooper and Cooper, 1946, p. 90).

Table 2—*Lower and Middle Ordovician terminology applicable to Rockingham County.*

Cooper and Cooper, 1946	Butts, 1940
Martinsburg formation	Martinsburg formation
Oranda formation	*Christiania* bed of Chambersburg limestone
Edinburg formation:	Chambersburg limestone
Liberty Hall and Lantz Mills facies	Athens formation
Botetourt limestone member of Edinburg formation	Whitesburg limestone
Lincolnshire limestone	Lenoir limestone
New Market limestone	Mosheim limestone
Beekmantown formation	Beekmantown formation

REVISION OF NOMENCLATURE

Cooper and Cooper (1946) recognized that the identification and correlation of some of the lower Middle Ordovician formations in Virginia were incorrect. They concluded that names such as Mosheim, Lenoir, Whitesburg, and Athens should not be applied in northern Virginia. Their revision of nomenclature was used by Edmundson (1958) and is followed in this report. An approximate correlation of the older names used by Butts (1940) and the newer names of Cooper and Cooper (1946) is shown in Table 2.

NEW MARKET LIMESTONE

Name and distribution—The New Market limestone, named by Cooper and Cooper (1946, p. 71) for exposures near New Market, Shenandoah County, is essentially the same as the Mosheim of Butts (1940) in northern Virginia. The formation has several belts of outcrop across Rockingham County and is present locally because of folding and of faulting.

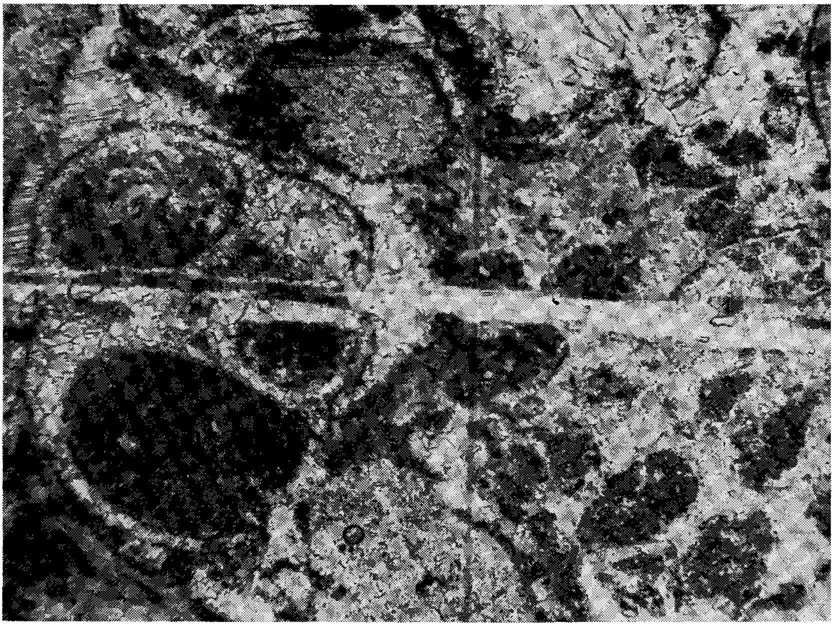
Character and thickness—The New Market consists mainly of dove-gray rather pure limestone; it is generally fairly massive and breaks with a sub-conchoidal fracture. On weathering, the surface commonly turns a distinctive white color with possibly a faint tinge of blue. An exception to the usual lithology was noted about 1½ miles south of Peales (Massanutten) Crossroads where dark, coarse, cherty beds, characteristic of the overlying Lincolnshire, were found intercalated in the lower beds of the New Market with definite lateral interfingering relations (Pl. 9A). The New Market is relatively free from chert in the eastern belts but the dense gray limestone beds in the western part of the county have considerable black chert at some outcrops.

A maximum thickness for the formation of 250 feet occurs near Edinburg, Shenandoah County, Virginia (Young, 1954). In Rockingham County the thickness varies but is generally between 50 feet and 200 feet.

Fossils and correlation—The most common fossil in the New Market is the coral *Tetradium syringoporoides*. Brachiopods are locally abundant, and cross-sections of fairly large gastropods may be seen on weathered surfaces of outcrops at a number of places. According to Butts (1940, p. 139) the New Market (Mosheim) may be a facies of the upper part of the Murfreesboro. The New Market is correlated with the Blackford formation of southwestern Virginia and with part of the type Lenoir of Tennessee (Cooper and Cooper, 1946).

Plate 8

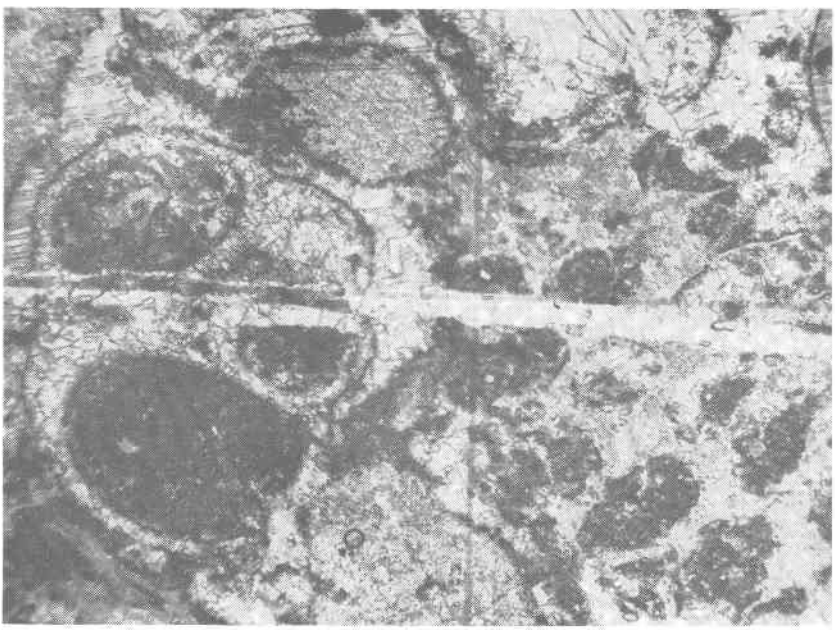
A. Photomicrograph of cross-section of bryozoan in limestone of Beekmantown formation near Mole Hill. x40.



B. Photomicrograph of cross-section of gastropod in limestone of Beekmantown formation near Mole Hill. Note cross-section of shelled form (brachiopod?) in upper right. x40.

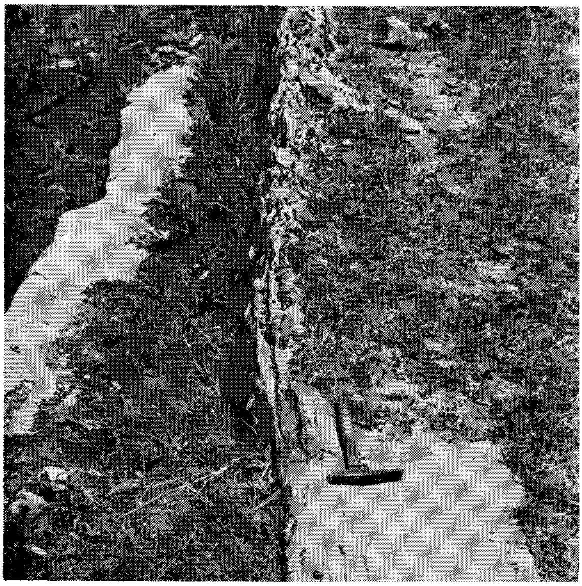
Plate 8

A. Photomicrograph of cross-section of bryozoan in limestone of Beekmantown formation near Mole Hill. x40.

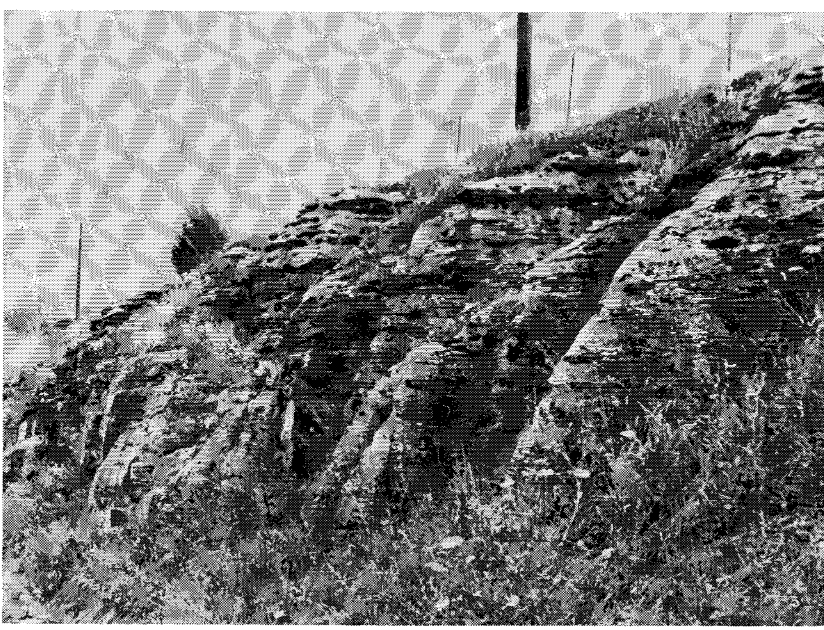


B. Photomicrograph of cross-section of gastropod in limestone of Beekmantown formation near Mole Hill. Note cross-section of shelled form (brachiopod?) in upper right. x40.

Plate 9

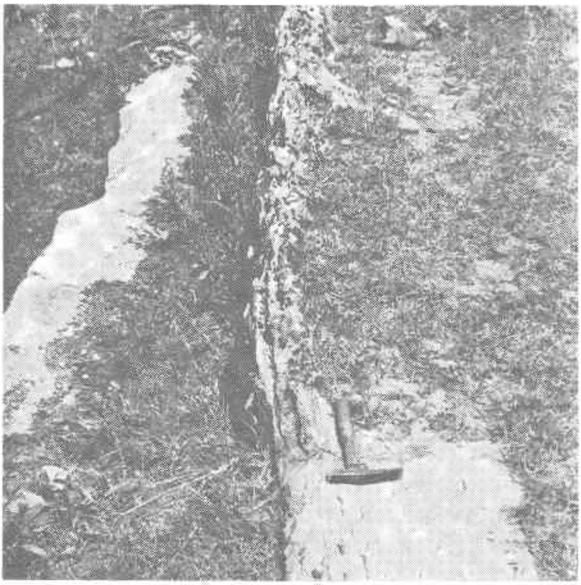


A. Lincolnshire lithology near base of New Market limestone about 1.5 miles south of Peales Crossroads.

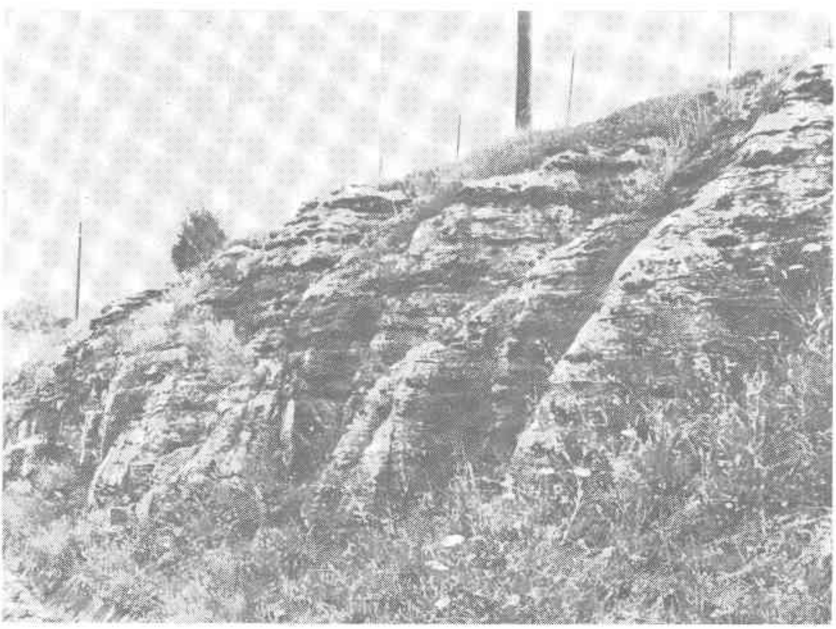


B. Bedded black chert in Lincolnshire limestone along U. S. Highway 33 about 1.5 miles west of Harrisonburg.

Plate 9



A. Lincolnshire lithology near base of New Market limestone about 1.5 miles south of Peales Crossroads.



B. Bedded black chert in Lincolnshire limestone along U. S. Highway 33 about 1.5 miles west of Harrisonburg.

LINCOLNSHIRE LIMESTONE

Name and distribution—Cooper and Prouty (1943, p. 863) named the Lincolnshire limestone from a creek in Tazewell County, Virginia. The Lincolnshire was re-defined by Cooper and Cooper (1946, p. 75) and the name is used in this report in the sense of the re-definition. The Lincolnshire is essentially the same as the Lenoir of northern Virginia of Butts (1940), except that the Lincolnshire includes some of the lower beds of the Chambersburg where the Chambersburg directly overlies the Lincolnshire. The distribution of the Lincolnshire in Rockingham County is almost identical with that of the New Market; rarely is one formation present and the other absent.

Character and thickness—The Lincolnshire is mainly a gray to black, medium-grained thick-bedded limestone. Black chert, which commonly occurs along or parallel to bedding planes, is a characteristic feature of the formation (Pl. 9B). The chert content apparently makes the formation fairly resistant to erosion, and in some areas the Lincolnshire may be traced by following a line of low ridges and hills. Some of the hills seem to be caused by a local reefy development in the formation, which has been silicified. One of these silicified "reefy" zones is ¼ mile north of Zion Church, about 2½ miles south of Broadway. Many of the beds in the Lincolnshire contain much fragmental fossil material which, in places, is chiefly crinoidal remains. Some exposures of the beds have a distinctly nodular structure after weathering, and red stains commonly are present in the nodular limestone. Lenses of fine-grained dove-gray limestone, typical of the underlying New Market, occur in some outcrops. In some places the contact between the Lincolnshire and New Market is fairly distinct; in other places the contact is vague. The maximum thickness of the Lincolnshire is about 200 feet at a locality south of Staunton, Augusta County (Cooper and Cooper, 1946, p. 76). In Rockingham County the thickness is variable but generally ranges between 50 feet and 150 feet.

Fossils and correlation—The Lincolnshire is moderately fossiliferous. Most useful in identifying the formation are *Dinorthis atavoides* and species of *Sowerbyella.* Cooper and Cooper (1946, p. 77) assigned no definite age to the Lincolnshire but suggested that it is post-Chazy. They think that the formation may be at least partly equivalent to a *Tetradium cellulosum*-bearing limestone near Marion, Pennsylvania.

EDINBURG FORMATION

Name and distribution—The Edinburg formation was named by Cooper and Cooper (1946, p. 78) from Edinburg, Shenandoah County, Virginia. The Edinburg is equivalent to the Whitesburg limestone, Athens formation, and the Chambersburg limestone of Butts (1940). In Rockingham County the Edinburg consists of a basal member, the Botetourt limestone, and two facies, the Liberty Hall and the Lantz Mills. The upper division of the formation, the St. Luke limestone member, is not present. The Edinburg formation crops out in several belts in the central Valley portion of Rockingham County.

Character and thickness—The Botetourt limestone member is present in places. It consists of a few feet to possibly 50 feet of dark, medium coarsely crystalline, commonly iron-stained limestone. Some beds are crowded with fragments of fossils, chiefly trilobites, crinoids, brachiopods, and bryozoans. At some localities north of Harrisonburg the upper part of the member consists of 20 feet, more or less, of limonite as seen in weathered exposures. Both facies of the Edinburg occur in Rockingham County. The Liberty Hall consists principally of dense black limestone and pink-weathering shale. Shaly beds are generally present at the base and may also occur at other horizons. The black limestone is subject to much intraformational folding and commonly veined with white calcite. The Lantz Mills facies overlies the Liberty Hall in places and in other places the two facies have interfingering relationships. The Lantz Mills facies is composed principally of cobbly to nodular buff-weathering limestone (Pl. 10A).

The belts of Edinburg bordering Massanutten Mountain are generally poorly exposed and an be examined in relatively few places. The formation in these belts differs markedly from the outcrops farther west in the county. Cooper and Cooper (1946) placed the belt of black shale and shaly limestone along the west side of the synclinal complex in the Liberty Hall facies. The belt on the east side of the synclinorium consists almost entirely of shale and is difficult to separate from the overlying Martinsburg shale.

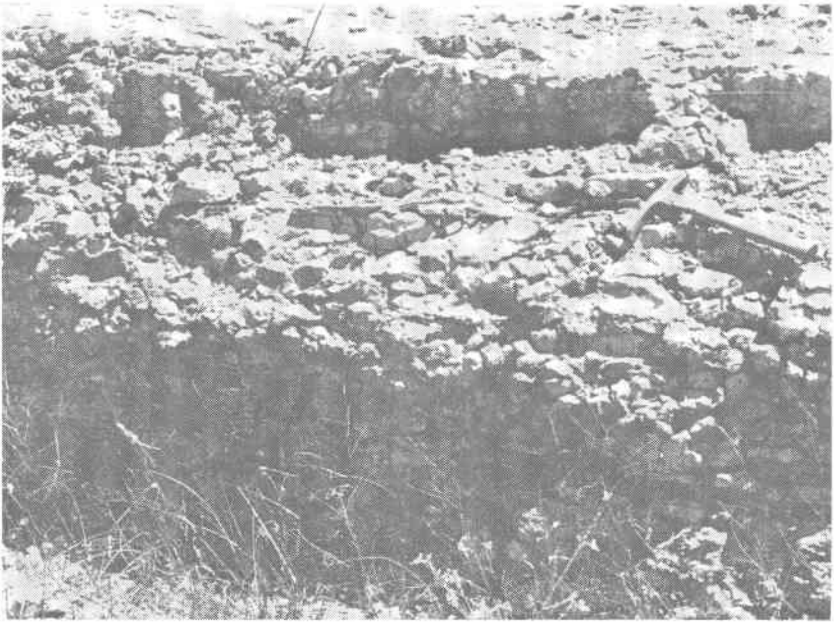
The Edinburg occurs as a single belt northwest of the Little North Mountain fault but the character and thickness of the formation are difficult to determine because exposures are poor. Outcrops about 2.5 miles southeast of Rawley Springs, in the Cooper Mountain area, indicate that the formation consists of dark *Nidulites*-bearing limestone and calcareous shale. Upon weathering, much of the limestone breaks down into irregular platy fragments. Near Sparkling Springs the formation consists chiefly of thin-bedded dark limestone and dark shale and this

Plate 10

A. Cobbly weathering Lantz Mills facies of Edinburg formation in quarry just west of Harrisonburg.

B. Platy or shaly appearance of weathered Elbrook dolomite near Keezletown.

Plate 10

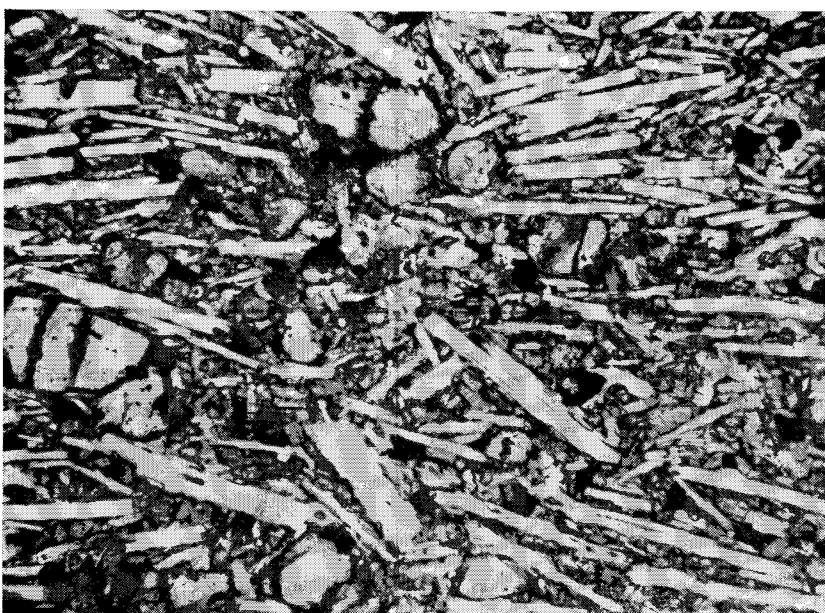


A. Cobbly weathering Lantz Mills facies of Edinburg formation in quarry just west of Harrisonburg.

B. Platy or shaly appearance of weathered Elbrook dolomite near Keezletown.

Plate 11

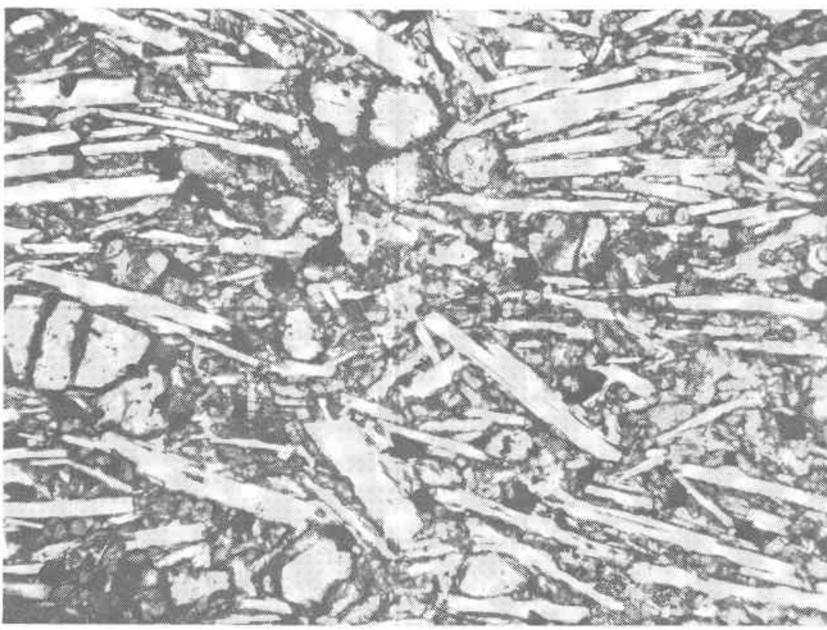
A. Columnar jointing in olivine basalt of Mole Hill about 4 miles west of Harrisonburg.



B. Photomicrograph of olivine basalt of Mole Hill. Augite and magnetite in the groundmass; other minerals include labradorite laths and olivine phenocrysts. x100.

Plate 11

A. Columnar jointing in olivine basalt of Mole Hill about 4 miles west of Harrisonburg.



B. Photomicrograph of olivine basalt of Mole Hill. Augite and magnetite in the groundmass; other minerals include labradorite laths and olivine phenocrysts. x100.

general character seems to be maintained to the northeast, although the formation is largely covered. North of Cootes Store the relative thinness of the Edinburg is probably partly a result of movement along the Little North Mountain fault.

The thickness of the Edinburg belt on the west flank of the Massanutten synclinorium is shown in two measured sections by Cooper and Cooper (1946, pp. 97, 99); one is 943 feet and the other is 833 feet. Thickness determinations of the formation west of this belt are difficult because of much intraformational folding and minor faulting. The thickness of the Edinburg formation 2 miles south of Harrisonburg is 1348 feet (Cooper and Cooper, 1946, p. 82). The maximum thickness of the formation in Rockingham County probably is about 1500 feet.

Fossils and correlation—In most of Rockingham County fossils in the Liberty Hall facies are largely confined to the shaly layers. The basal shales contain species of the *Nemagraptus gracilis* fauna which correlate them with the Normanskill shale of New York. *Nidulites pyriformis*, *Echinosphaerites aurantium*, and species of *Christiania* are common and are useful in identifying the Edinburg. The occurrence of *Nidulites pyriformis* has been the subject of some controversy. The most important fossil for the identification of the Chambersburg is *Nidulites pyriformis* (Butts, 1940, p. 200). The Chambersburg is above the Athens and below the Martinsburg shale. Cooper and Cooper (1946) stated that *Nidulites pyriformis* is a "facies fossil" and that its presence or absence anywhere between the *Dinorthis atavoides* beds and the *Reuschella* zone probably was determined by local conditions of deposition. They said that *Nidulites* is generally sparse in cobbly beds, rare in dense black limestone, and abundant in a certain variety of Middle Ordovician limestone which is finely granular, thin-bedded, and weathers smoke-gray. However, they noted that *Nidulites* is abundant in black, cobbly, argillaceous limestone near Harrisonburg. Young (1954) found *Nidulites* to be locally abundant in both facies of the Edinburg formation in the Edinburg quadrangle, Virginia-West Virginia. In and around Harrisonburg the writer found *Nidulites* to be fairly abundant in some exposures of cobbly-weathering limestone and rare in dense black limestone of the Edinburg. Recently, studies of small silicified trilobites from the Edinburg and adjacent formations have been made on material from Shenandoah, Rockingham, and Augusta counties, Virginia (Whittington and Evitt, 1953; Whittington, 1956, 1959). Relations between these trilobites and certain European genera were discussed by Whittington (1959, p. 390).

ORANDA FORMATION

Named and distribution—Oranda formation was named by Cooper and Cooper (1946, p. 86) from a locality near Strasburg, Shenandoah County, Virginia. The Oranda is the same as the "*Christiania*" bed (upper Chambersburg) of Butts (1940) and is mapped with the Edinburg in this report.

Character and thickness—The Oranda is composed mainly of siltstone and argillaceous limestone with some "metabentonites." At the type section the Oranda is 56 feet thick but lesser thicknesses are more common. The Oranda apparently is absent southeast of Harrisonburg (Cooper and Cooper, 1946, p. 87).

Fossils and correlation—*Reuschella edsoni* and species of *Christiania* and *Bimuria* are commonly found in the Oranda. The formation is correlated with the *Christiania* bed of the Chambersburg limestone of Pennsylvania, and with the basal member of the Sherman Fall limestone of New York.

MARTINSBURG SHALE

Name and distribution—Geiger and Keith (1891, p. 161) named the Martinsburg shale from Martinsburg, West Virginia. The Martinsburg is present in several synclinal belts in the Valley area and commonly is the youngest rock preserved in the folds, but in the Massanutten synclinal structure, younger rocks lie above the Martinsburg. The Martinsburg forms the northwest side of the Little North Mountain fault for more than 15 miles in the county. Some Martinsburg is exposed in the center of an anticline about 3½ miles east of Bergton.

Character and thickness—The Martinsburg consists mainly of shale and calcareous shale but layers of cobbly-weathering limestone may occur at the base and at irregular intervals throughout much of the formation. Beds of siltstone are common and sandstone beds occur locally. Thornton (1953) found about 40 feet of brown sandstone above the Martinsburg and below the Massanutten sandstone which may be an unfossiliferous development of the upper part of the Martinsburg. The writer found about 50 feet to 100 feet of greenish-gray sandstone, apparently unfossiliferous, at Runkles (Ruckles) Gap in Massanutten Mountain. The sandstone found by Thornton and that found by the writer could be an unfossiliferous or sparsely fossiliferous near-shore development of the *Orthorhynchula* zone of Butts (1940). Near the base of the southwest side of Piney Mountain, one mile northeast of McGaheysville, about 100 feet of thick-bedded, fine-grained, greenish-gray sandstone is exposed. A thorough search yielded several small poorly preserved brachiopods that were not readily identifiable. On the east side of Massanutten Mountain, between East Point and Mt. Sinai Church, a considerable thickness of beds of greenish siltstone and sandstone is exposed.

No accurate thickness measurements of the Martinsburg have been made because of internal folding and lack of complete exposures. Spencer (1896, p. 9) estimated a thickness of about 2800 feet for the formation and Thornton (1953) conservatively estimated a thickness of about 1000 feet plus. In Rockingham County a thickness of between 1500 feet and 3000 feet is suggested for the Martinsburg.

Fossils and correlation—The Martinsburg may be divided into three parts on the basis of paleontology: Trenton, Eden, and Maysville. *Diplograptus amplexicaulis* and *Sinuites cancellatus* may be used to distinguish the lowest zone (Trenton), and species of *Cryptolithus* to indicate the Eden. The most distinctive zone is the top which is marked by abundant *Orthorhynchula linneyi* from central Pennsylvania to eastern Tennessee (Butts, 1940, p. 208). The lower part of the Martinsburg correlates with the Trenton limestone of New York, and the middle and upper part with the Eden and Maysville of Ohio.

OSWEGO SANDSTONE

Name and distribution—The Oswego sandstone was named by Vanuxem (1842, p. 67) from Oswego, New York. In Rockingham County the formation crops out in one belt in Little North Mountain and in Cooper Mountain. The exposure in Cooper Mountain (Giants Grave) is the southernmost limit of outcrop of the Oswego in Virginia (Butts, 1940, p. 220). Near the center of an anticline about 3½ miles east of Bergton the Oswego is exposed.

Character and thickness—In Rockingham County the Oswego is principally a massive, thick-bedded, greenish-to bluish-gray sandstone and some beds strongly resemble quartzite. Brown iron-specks are scattered through much of the formation. Clay balls or pellets, commonly several mm in diameter or larger, occur at scattered horizons. Where these clay pellets have weathered out the resulting depressions commonly resemble molds of fossils. Green shale and some red shale partings occur throughout the formation.

The thickness of the formation in Little North Mountain cannot be determined because of faulting and cover. The section at Brocks Gap is 370 feet thick as measured along the level ground but there is a fault between the Oswego and the stratigraphically lower Martinsburg shale. It is estimated that an additional 80 feet or so of the Oswego occurs to the east of the intersection of the fault with the ground surface at the level of the highway, but the exposure is a sheer rock cliff and out of reach. The total thickness of the Oswego here is estimated at approximately 450 feet. The Oswego is 507 feet thick at this locality according to Butts (1940, pp. 219-220). The writer is in agreement with Butts' identification of the Oswego here; however, Butts does not mention the faulting between the Oswego and the Martinsburg.

Woodward (1955) measured a section of the Oswego and several younger formations at Brocks Gap, but differed with Butts in the identification of some of the formations. He (Woodward) recognized the fault contact between the Oswego and the Martinsburg. Woodward made two possible interpretations of the section at Brocks Gap; following one interpretation the Oswego is 377 feet thick, and using the alternate interpretation the thickness is 507 feet.

On the Geologic Map of the Appalachian Valley in Virginia (1933) the sandstone in Cooper Mountain is shown as Tuscarora (Clinch); however, Butts (1940, p. 220) called it Oswego. The writer thinks it is chiefly Oswego. The bottom of the Oswego here is difficult to determine accurately because no fossils could be found in the sandstone in the stratigraphic position of the *Orthorhynchula* zone of the Martinsburg. Farther up in the section is a covered area 40 feet wide and also there is faulting of unknown but apparently small displacement. Above the apparently unfossiliferous *Orthorhynchula* bed-type sandstone, all 688 feet of dense mostly thick-bedded sandstone may be Oswego. About 45 feet from the top is a shear that dips about 60° to the west, and drag indicates that the northwest block moved toward the southeast. West of this fault the lithology more nearly resembles the Clinch than the Oswego. If this identification is correct, the Oswego-Juniata unit is about 643 feet thick and the Clinch about 45 feet thick at the south end of Cooper Mountain. Along Little North Mountain the Oswego varies in thickness and apparently is absent in places. The thickness of the Oswego is approximately 300 feet in the Bergton area (Young and Harnsberger, 1955).

Fossils and correlation—According to Butts (1940, p. 221) the Oswego is unfossiliferous in Virginia and no fossils were found by the writer in the formation in Rockingham County. The formation, which is correlated with the Oswego of New York by Butts on lithology and stratigraphic position, has characteristic upper Maysville fossils below and the red Juniata shales above.

JUNIATA FORMATION

Name and distribution—Use of the name Juniata formation first occurs in U. S. Geological Survey Folio 28 (1896) and credit for the name is given to N. H. Darton. No type locality was designated and the reason for the selection of the name was not stated; however, Butts (1940, p. 221) said that the formation was named for the Juniata River in Pennsylvania. In this report the Juniata is mapped with the Oswego because of the difficulty in identifying the formations separately along Little North Mountain.

In Rockingham County exposures of the Juniata occur in Little North Mountain and near the center of an anticline about 3½ miles east of Bergton. Northeast of Brocks Gap the formation crops out at or near the top of Little North Mountain and apparently extends to the Shenandoah County line. Southwest of Brocks Gap it appears to either change character and become indistinguishable from the Oswego, or to thin and gradually disappear. Woodward (1955) said that at Brocks Gap good Clinton ostracodes were found in the beds called Juniata by Butts (1940); however, the writer could not find any ostracodes and has followed the identification of Butts.

Character and thickness—The character of the formation cannot be well observed locally because of lack of good exposures. In the original description (U. S. G. S. Folio 28) the formation is described as follows: The rocks of the Juniata formation " . . . are red sandstones and shales, which are interbedded in no regular succession. The sandstones are hard, moderately coarse grained, and in part cross-bedded. They vary in thickness from 1 to 30 feet, and are mainly in beds from 1 to 4 feet thick. The shales vary from a thin parting between sandstone layers to beds 6 or 8 feet thick. Much of the formation consists of alternations of 4 to 5 feet of shales and 8 to 10 feet of sandstone." According to Butts (1940, p. 222): "The Juniata formation is composed mainly of bright red shale or mudrock and beds of brown to red sandstone. A few layers of gray sandstone occur in places near the top. Its distinctive feature is the red color."

The thickness of the formation in Little North Mountain appears to be 200 feet or less (Butts, 1940, p. 228). Stratigraphically above the Oswego, in the Juniata horizon, at Brocks Gap there is a covered area of 190 feet followed by about 20 feet of gray sandstone, red mudrock, and green shale. The thickness of the Juniata interval at Brocks Gap is thus about 210 feet. Young and Harnsberger (1955, p. 323) gave 250 feet as the approximate thickness of the Juniata formation in the Bergton area.

Fossils and correlation—The formation in this area does not appear to contain any recognizable fossils. The Juniata is correlated with the Queenston shale of New York and generally is considered to be of upper Ordovician age (Wilmarth, 1938, p. 1060).

SILURIAN SYSTEM

CLINCH (TUSCARORA) SANDSTONE (QUARTZITE)

Name and distribution—The Tuscarora quartzite was named by Darton in U. S. G. S. Folio 28 (1896). No type locality was given but Butts (1940, p. 229) said that the name was derived from Tuscarora Mountain, Pennsylvania. The Clinch was named for Clinch Mountain, Tennessee by Safford (1869). In this report the name Clinch is used, following the recommendation of Butts (1940, p. 229): "In order to promote uniformity of stratigraphic usage, it would be desirable to discard the name Tuscarora and use only the name Clinch throughout the Valley, because the use of two names suggests two formations, whereas only one is present."

The Clinch crops out in a single belt along the top and southwest side of Little North Mountain and also is exposed in the Adams Run anticline northeast of Fulks Run. Part of the Massanutten sandstone, of the Massanutten Mountain area, is generally regarded as being equivalent to the Clinch.

Character and thickness—The Clinch sandstone is mainly a white to gray, massive, quartz sandstone with a silica cement (orthoquartzite). Some beds, especially near the base, are conglomeratic and contain quartz pebbles up to half an inch or more in diameter in a quartz sand matrix. Thin shale partings are present at various horizons.

In Little North Mountain in Frederick and Shenandoah counties the thickness of the Clinch varies from 200 feet to only a few feet, according to Butts (1940, p. 234). The formation appears to be present the entire length of Little North Mountain in Rockingham County and the thickness ranges from 53 feet in Brocks Gap to possibly 130 feet at Hopkins Gap. However, the top of the Clinch cannot be determined accurately at Hopkins Gap so the thickness may be considerably less than 130 feet. In the Bergton area the thickness of the Clinch is about 200 feet (Young and Harnsberger, 1945, p. 323). In Massanutten Mountain the writer found 645 feet of Massanutten (Clinch-Clinton) sandstone at Runkles Gap, but an unknown amount of this probably belongs to the Clinton formation.

Fossils and correlation—Butts (1940, p. 235) said that *Scolithus verticalis* and *Arthrophycus alleghaniensis* occur in the Clinch, but no fossils were observed in the formation by the writer in Rockingham County. The Clinch is the same as the Tuscarora of Pennsylvania and Maryland, and the formation is correlated with the Albion sandstone of New York and possibly with the Brassfield (limestone) of Ohio (Butts, 1940). The Clinch was once placed in the Ordovician but long has been considered to be of early Silurian age.

CLINTON FORMATION

Name and distribution—T. A. Conrad applied the name Clinton group to beds underlying the Niagara shale and overlying the Niagara sandstone (Wilmarth, 1938). The Clinton occurs in Little North Mountain, in the Adams Run anticline that extends northeast from Fulks Run, and as part of the Massanutten sandstone in Massanutten Mountain.

Character and thickness—The Clinton in Virginia typically is composed of shale and sandstone; a more complete description was given by Butts (1940, pp. 237-250). Because of poor exposures the character of the formation cannot be determined accurately in Little North Mountain. Along a road across Little North Mountain, about one mile southwest of the Shenandoah County line, approximately 100 feet of red sandstone and red and green shale of the lower Clinton is exposed. Some of the sandstone beds are highly ferruginous and the iron-oxide appears to be mostly hematite. At Hopkins Gap in Little North Mountain the contacts are covered but approximately 150 feet of mainly the lower part of the Clinton is rather poorly exposed. Weathered outcrops contain gray and red sandstone, some shale, and some highly ferruginous sandstone. There is about 30 feet of white to gray dense sandstone which may represent the Keefer member. The Keefer sandstone member seems to be lenticular along Little North Mountain in Rockingham County. The thickness of the Clinton west of Little North Mountain is about 500 feet (Young and Harnsberger, 1955, p. 323). The thickness of the Clinton in the Massanutten Mountain area is unknown because in that area the formation is indistinguishable from the Clinch part of the Massanutten sandstone. The Clinton horizon is mostly covered at Brocks Gap in Little North Mountain but the width of the stratigraphic interval indicates a thickness of about 270 feet for the formation.

Fossils and correlation—In Virginia the Clinton formation is sparsely fossiliferous and according to Butts (1940, pp. 248-249) the most abundant fossils in the formation are brachiopods and ostracodes. Clinton ostracodes have been reported from the section at Brocks Gap (Woodward, 1955) but none was seen by the writer. The Clinton of Rockingham County is substantially equivalent to the Clinton in its type section in New York.

MASSANUTTEN SANDSTONE

Name and distribution—The term "Massanutten sandstone" as here used applies to the thick series of sandstones, quartzites, and conglomerates of the Massanutten Mountain area, overlying the unfossiliferous or sparsely fossiliferous sandstone at the top of the Martinsburg and lying below the Bloomsburg red beds. The original definition by Geiger and Keith (1891) is invalid because of a misidentification, which was later corrected (Keith, 1894). Spencer (1897) used "Massanutten sandstone" in the same sense as the term is used in this report. Darton (1899) used "Massanutten sandstone" to include the Juniata formation, Tuscarora quartzite, and the Cacapon sandstone. Butts (1940) considered the Massanutten sandstone of Massanutten Mountain as probably the equivalent in time of the Clinch and Clinton formations. Thornton (1953) assigned the exposure of the Massanutten sandstone at Burners Gap, 3 miles N. 25° W. of Hamburg, Page County, as the type locality and gave a measured section. The Massanutten sandstone occurs only in the Massanutten Mountain area, where it is the principal ridge-forming rock.

Character and thickness—The formation consists principally of white orthoquartzite and fine-grained sandstone. There is some quartz-pebble conglomerate, especially at the base, and there are a few lenticular beds of siltstone and shale in places. Cross-bedding is conspicuous in some sandstone beds. Thornton (1953), in a heavy-mineral separation, found that leucoxene, hematite, zircon, and tourmaline make up more than 90% of the heavy minerals present and other minerals identified include staurolite, rutile, and hornblende.

The thickness of the Massanutten sandstone at Burners Gap is 700 feet (Thornton, 1953). Young (1954) stated that the formation is 840 feet thick at Edinburg Gap. In Rockingham County the Massanutten sandstone is 646 feet thick at Runkles (Ruckles) Gap, on the east side of the Mountain, and about 529 feet thick at Fridley Gap, on the west side of the mountain, but some of the beds at the top of the formation may be missing at Fridley Gap. The thickness of the formation in the county probably varies from about 500 feet to about 700 feet.

Fossils and correlation—The Massanutten sandstone is essentially unfossiliferous; the only reported fossils are a few specimens of

Arthrophycus alleghaniensis and *Scolithus verticalis.* No fossils were found by the writer in the Massanutten sandstone in Rockingham County. Because of its isolated position and lack of good fossils, the exact correlation of the formation is uncertain. Butts (1940, p. 234) said: "In Massanutten Mountain the Tuscarora-Clinton (Massanutten) is 500 feet thick, but how much is Tuscarora is not known." Because of the stratigraphic position, reported fossil content, and lithology the writer agrees with Butts that the Massanutten sandstone probably correlates with the Clinch (Tuscarora) and the Clinton. It is difficult to say how much of the Massanutten sandstone correlates with the Clinch and how much correlates with the Clinton.

CAYUGA GROUP

Name and distribution—The Cayuga group was named from Cayuga County, New York (Clarke and Schuchert, 1899). In Virginia, the formations included in the group are from oldest to youngest: McKenzie, Bloomsburg, Wills Creek, and Tonoloway (Butts, 1940). The Cayuga group crops out on the west side of Little North Mountain, and on the flanks of the Adams Run anticline, from near Fulks Run northeast to the Shenandoah County line. The Bloomsburg and Tonoloway occur in the Massanutten Mountain area. Individual formations within the group are not distinguished on the geologic map.

Character and thickness—Along Little North Mountain exposures of the Cayuga group are so poor that individual formations cannot definitely be recognized. A finely-laminated limestone, probably Tonoloway, crops out in a few places. In Little North Mountain the lower and upper contacts are not exposed, and the group is shown on the geologic map as occupying the interval between definite Clinton beds and the coarse crinoidal or cherty Devonian limestones. The thickness of the Cayuga group at Brocks Gap is estimated to be about 220 feet and several miles to the northeast, near the Shenandoah County line, the Cayuga group seems to be present but somewhat thinner than at Brocks Gap. Southwest of Brocks Gap there are a few exposures of finely laminated limestone but no reliable estimate can be made of its approximate thickness. In the area of the Adams Run anticline the thickness of the Cayuga group is about 600 feet (Young and Harnsberger, 1955, p. 323).

Fossils and age—No fossils were found in the Cayuga group in Little North Mountain and the Silurian age is assigned to the group from its position stratigraphically above the Clinton formation and below the cherty Devonian limestones.

BLOOMSBURG FORMATION

Name and distribution—White (1883) named the Bloomsburg formation from exposures at Bloomsburg, Pennsylvania. The Bloomsburg is mapped as part of the Cayuga group in the Massanutten Mountain area, but it is not certain that the formation is present in the Cayuga group to the west.

Character and thickness—In the Massanutten Mountain area the Bloomsburg consists chiefly of red sandstones, siltstone, and shale, and contact with the underlying Massanutten sandstone commonly can be determined readily. In Harshberger Gap of Massanutten Mountain, Butts (1940, p. 255) suggested a possible thickness of 340 feet for the Bloomsburg. Thornton (1953) estimated the thickness to be between 200 feet and 600 feet. At Runkles Gap in Massanutten Mountain only the lower 74 feet of the Bloomsburg is exposed.

Fossils and correlation—The Bloomsburg apparently is unfossiliferous in Rockingham County. Woodward (1941) used the term "Bloomsburg facies" because of a lack of a constant stratigraphic trend. The Bloomsburg may correlate with the Bloomsburg member of the Wills Creek formation of central Pennsylvania.

TONOLOWAY LIMESTONE

Name and distribution—The formation was named by Ulrich (1911) from exposures in Washington County, Maryland. The Tonoloway is present along Little North Mountain and in the Adams Run anticline, extending northeast of Fulks Run, and is mapped as part of the Cayuga group. In Massanutten Mountain a thin limestone overlying the Bloomsburg was correlated with the Tonoloway (?) by Thornton (1953). In this report the Catherine limestone of Thornton (1953) is included with the Tonoloway (?) of the Massanutten Mountain area.

Character and thickness—The Tonoloway (?) in Massanutten Mountain is a gray shaly limestone that weathers to a light gray or white color. The limestone, which commonly is fine-grained and mud-cracked, is approximately 50 feet thick. The Catherine limestone was described by Thornton (1953) as a fine-to medium-grained gray or pinkish clastic limestone with a few layers of siltstone and with a thickness that is commonly between 30 feet and 80 feet.

Fossils and correlation—No fossils were found in the Tonoloway (?) of Massanutten Mountain in Rockingham County, but the formation probably correlates with the Tonoloway limestone of West Virginia and Maryland. Only broken fossil fragments were found in the Catherine limestone, the age of which is assumed to be upper Silurian (Thornton, 1953).

DEVONIAN SYSTEM

HELDERBERG LIMESTONE (HELDERBERG GROUP, UNDIVIDED)

Name and distribution—The Helderberg was named by Conrad (1839) from the Helderberg Mountains of Albany and Schoharie counties, New York. Exposures of the Helderberg in Little North Mountain are generally so poor that the individual formations cannot be distinguished. At Brocks Gap in Little North Mountain the exposed beds just below the Ridgeley consist of more than 200 feet of nearly vertical limestone. The limestone is abundantly fossiliferous in part and contains closely spaced layers of black chert parallel to bedding. The total thickness of the Helderberg horizon here is estimated at 450 feet, but some of this may be in the Cayuga group. About a mile north of Brocks Gap, along the west side of the mountain, there is about 200 feet to 300 feet of crystalline limestone and fossiliferous limestone with layers of black chert, in the stratigraphic position of the Helderberg. At Hopkins Gap, 10 miles southwest of Brocks Gap, the exposed Helderberg horizon is represented by about 50 feet of bedded black chert. The associated limestone has been dissolved and the outcrop is weathered and covered to such an extent that the thickness of the formation cannot be determined.

In the Adams Run anticline, about 2 or 3 miles northwest of Little North Mountain, a good exposure of the Helderberg is along State Highway 259 about 0.7 mile west of Fulks Run. The Fulks Run section as given by Swartz (1929) is as follows: the Helderberg group (Keyser limestone, some Coeymans?, and New Scotland limestone) overlies the Tonoloway limestone, and the Helderberg group is overlain by the Shriver chert and the Ridgeley sandstone. The thickness of the Helderberg here is about 206 feet and the Shriver chert about 56 feet (Swartz, 1929). Woodward (1943) at this same locality showed the Tonoloway limestone as overlain in ascending order by: Keyser limestone, Coeymans limestone, New Scotland limestone, Port Ewen limestone (cherty), and Port Jervis limestone, all in the Helderberg group. The total thickness here is about 265 feet (Woodward, 1955). According to Young and Harnsberger (1955, p. 323) the Helderberg at Fulks Run is made up of the Coeymans limestone, New Scotland limestone, and the Becraft formation (possibly equivalent to the Shriver chert of other areas), with a total thickness of about 150 feet.

The following discussion will describe the formations of the Helderberg as listed by Woodward (1943 and 1955).

KEYSER LIMESTONE

The Keyser limestone was named by Swartz (1913) from Keyser, West Virginia. The lower part of the formation is separated from the upper part by the Big Mountain shale member. The Keyser consists largely of blue to dark gray limestone much of which is massive and coarsely crystalline. Beds of crinoidal limestone, gnarly limestone, and shaly, thin-bedded limestone all occur in the formation. The Big Mountain shale member has some coarsely crystalline crinoidal limestone beds. At Fulks Run, Woodward (1943) measured the thickness of the lower Keyser as 37 feet, the Big Mountain shale member as 35 feet, and the upper Keyser as 35 feet. Some of the fossils that occur in the Keyser include: *Favosites helderbergiae*, *Rensselaeria mutabilis*, *Whitfieldella prosseri*, *Chonetes jerseyensis*, *Merista typa*, and *Camarotoechia gigantia* (Woodward, 1943).

COEYMANS LIMESTONE

The Coeymans limestone was named by Clarke and Schuchert (1899) for Coeymans, New York. The formation is commonly massive limestone crowded with crinoid remains and the thickness in the area of this report is approximately 20 feet. Few identifiable fossils have been collected in Virginia other than *Gipidula coeymanensis* and possibly *Meristella arcuata*.

NEW SCOTLAND LIMESTONE

The New Scotland limestone was named by Clarke and Schuchert (1899) for New Scotland, New York. The formation is an argillaceous and siliceous nodular limestone commonly containing much chert and some highly fossiliferous beds. The thickness of the New Scotland in Rockingham County is probably about 35 feet. Some of the fossils that have been listed as occurring in the formation are: *Delthyris perlamellosus*, *Leptaena rhomboidalis*, and *Streptelasma strictum* (Woodward, 1943).

PORT EWEN LIMESTONE

The Port Ewen limestone was named by Clarke (1903) from Port Ewen, New York. The formation is partly equivalent to the Shriver chert and is chiefly a strongly siliceous or cherty limestone. The thickness of the Port Ewen at Fulks Run is about 95 feet (Woodward, 1943).

PORT JERVIS LIMESTONE

The Port Jervis limestone, named by Chadwick (1908), represents the Shriver chert, in part, or the Becraft limestone horizon. The formation, which is generally similar to the underlying Port Ewen, has a thickness of about 10 feet at Fulks Run (Woodward, 1943).

RIDGELEY SANDSTONE

Name and distribution—The Ridgeley sandstone was named by Swartz (1913) from Ridgeley, Mineral County, Maryland. The Ridgeley in Rockingham County is equivalent to the Oriskany sandstone of Butts (1940). In Pennsylvania, the Guidebook for Field Trips, Pittsburgh Meeting of Geological Society of America (1959) lists the Ridgeley and the Shriver as members of the Oriskany formation. According to Woodward (1943), it has not been proved that the Ridgeley of the Appalachians is the exact equivalent of the Oriskany of New York. In Rockingham County the chief exposures of the Ridgeley occur on the west side of Little North Mountain, and in the Adams Run anticline extending northeast from near Fulks Run.

Character and thickness—The Ridgeley is a coarse-grained blue-gray to dark-gray sandstone with some calcareous cement. In some places the rock is a quartz pebble conglomerate with pebbles up to one-half inch in diameter, and in other places the grains are the size of wheat and the rock is described as a wheat grain conglomerate. Many of the sand grains are frosted suggesting that they were transported by wind. In a microscopic study, Martens (1939) found the following accessory minerals: pyrite, barite, sphalerite, zircron, tourmaline, and rutile. Many exposures of Ridgeley contain abundant fossils, especially brachiopods.

At Brocks Gap in Little North Mountain the Ridgeley (Pl. 5B) is about 55 feet thick, but there is a transition zone, approximately 10 feet in thickness, with the underlying Helderberg. North of Brocks Gap, along a road across Little North Mountain about a mile south of the Shenandoah County line, the Ridgeley is about 140 feet thick. At Hopkins Gap, about 10 miles south of Brocks Gap, the Ridgeley is estimated to be between 50 feet and 100 feet in thickness. In the Bergton area the thickness of the Ridgeley is about 75 feet to 100 feet (Young and Harnsberger, 1955). The thickness of the formation about a mile west of Fulks Run is approximately 145 feet (Woodward, 1943 and 1955).

Fossils and correlation—*Costispirifer arenosus* and several species of *Platyceras* are commonly abundant in the Ridgeley (Young and Harnsberger, 1955). Woodward (1943) divided the Ridgeley into two horizons, an earlier horizon with "*Spirifer*" *murchisoni* and a later horizon with "*Spirifer*" *arenosus*. The Ridgeley is the approximate equivalent of the Oriskany of earlier reports in Pennsylvania and New York.

NEEDMORE SHALE

Name and distribution—The Needmore shale was named by Willard (1939) from Needmore, Fulton County, Pennsylvania. The Needmore shale of Rockingham County is essentially the same as the Onondaga of Butts (1940), and of Young and Harnsberger (1955). The Needmore is exposed in the Massanutten Mountain area and on the flanks of the Adams Run anticline and may be present overlying the Ridgeley on the west side of Little North Mountain, but it is not exposed. The formation was mapped with the Millboro shale and is included in areas designated by Dmo on the geologic map.

Character and thickness—The Needmore is a dark-green or olive-gray partly calcareous clay shale that commonly weathers to a non-fissile, chalky, yellowish rock. The maximum thickness of the formation in the county probably is about 100 feet.

Fossils and correlation—Some of the fossils that have been identified from the formation are: *Phacops cristata, Bollia ungula,* and *Coelospira acutiplicata.* According to Woodward (1943) the Needmore is the partial equivalent to the Onondaga of New York, and is the same as the Onondaga shale of recent reports on areas in the Appalachians of Virginia.

MILLBORO SHALE

Name and distribution—The Millboro shale was named by Butts (1940) from exposures at Millboro Springs, Bath County, Virginia. The name is used to include the Marcellus and Naples in areas where the Hamilton is absent. The Millboro is exposed on the west side of Little North Mountain and on the flanks of the Adams Run anticline.

Character and thickness—The Millboro is a black fissile shale that commonly weathers to a light gray or pinkish clay shale. When fresh the black shale may easily be broken into thin flakes and into small sharp fragments. Structurally the shale is very weak and deforms readily. Young and Harnsberger (1955) noted the local occurrence of 10 feet to 20 feet of dark limestone near the middle of the Millboro and said that: "Limestone in similar stratigraphic position has been reported from West Virginia and the problem of its correlation is discussed by by Woodward (1943, pp. 387-89). It appears that this limestone is a lentil in the upper Marcellus or lower Naples, as there is no noticeable faunal change."

The thickness of the Millboro in Virginia varies from 200 feet to 1000 feet (Butts, 1940, p. 312). Young and Harnsberger (1955, p. 323) gave an approximate thickness of 400 feet to 500 feet for the formation in the Bergton area. The thickness of the unit along the west side of Little North Mountain cannot be determined because of poor exposures and probable close folding and faulting.

Fossils and correlation—The lower 100 feet of Millboro commonly has Marcellus type fossils and the upper 100 feet of Millboro commonly contains fossils of Naples age. Many of the fossils in the Millboro are of small size and some have been replaced by pyrite. The Marcellus age of part of the Millboro is indicated by the presence of such fossils as *Leiorhynchus limitare* and *Actinopteria muricata.* The occurrence of *Buchiola retrostriata, Paracardium doris,* and *Probeloceras lutheri* suggest the Naples age of the upper part of the Millboro (Butts, 1940, pp. 308-312).

BRALLIER SHALE

Name and distribution—The Brallier shale was named by Butts (1918) from Brallier Station, 5 miles northeast of Everett, Bedford County, Pennsylvania. The Brallier is on the northwest side of the Little North Mountain fault in the southwestern part of Rockingham County, and the formation occurs in several belts in the northwestern part of the county as a result of folding.

Character and thickness—The Brallier conformably overlies the Naples horizon of the Millboro, but the formations are distinctly different in character. The Brallier was described by Butts (1940, p. 317) as ". . . a rather monotonous mass of subfissile, stiff, more or less sandy and micaceous green shale, commonly with uneven or dimpled surfaces in which are interbedded layers of very fine-grained, evenly thin-bedded, and blocky-jointed greenish sandstone." The boundary between the Brallier and the overlying Chemung is gradational within a zone of 100 feet or more thickness and the top of the Brallier is placed just below the stratigraphically lowest bed containing large fossils of Chemung type. In Frederick County the thickness of the Brallier is about 1500 feet (Butts, 1940, p. 319). Young and Harnsberger (1955, p. 323) gave 1200 feet as the approximate thickness of the Brallier in the Bergton area.

Fossils and correlation—In the Brallier fossils are small, scarce, and difficult to find. Some of the forms that have been collected from the formation are: *Pteridichnites biseriatus, Leiorhynchus globuliforme, Buchiola retrostriata,* and *Probeloceras lutheri.* Butts (1940, p. 320) stated that *Pteridichnites biseriatus* is fairly common in the Brallier and may be used as a guide fossil, and specimens of *Pteridichnites biseriatus* were found by the writer in the Brallier of Rockingham County. According to Woodward (1943, p. 445) the formation is correlated with the Brallier of West Virginia and with the Woodmont shale of Maryland.

CHEMUNG FORMATION

Name and distribution—The Chemung was named by Hall (1839) from an area near Elmira, New York. In the southwestern part of Rockingham County the Chemung crops out in a fairly narrow belt northwest of the Little North Mountain fault. In northwestern Rockingham County, west of Fulks Run, the Chemung is exposed in an area several miles in width. Good outcrops of Chemung occur along the State Highway 820 east of Bergton, and along Dry River southeast of Rawley Springs.

Character and thickness—The Chemung consists principally of fairly thick-bedded, gray to greenish silty sandstones, and brown to gray shales. Most of the shale in the Chemung is softer and less fissile than shale in the Brallier. In places, there are a few thin beds of quartz conglomerate and near the upper boundary of the Chemung there are commonly red sandstones and shales which resemble the lower Hampshire beds. The Chemung usually is described as a fossiliferous formation, but in some areas fossils are scarce and difficult to locate. Commonly, fossiliferous horizons contain an abundance of specimens. The approximate thickness of the Chemung throughout the Valley of Virginia is 2000 feet (Butts, 1940, p. 329). The thickness of the Chemung in the Bergton area is about 1900 feet (Young and Harnsberger, 1955, p. 323). At Rawley Springs the formation is between 2000 feet and 2500 feet in thickness.

Fossils and correlation—Large spiriferoid brachiopods, especially *Platyrachella mesastrialis* and *Cyrtospirifer disjunctus*, are characteristic of the Chemung according to Young and Harnsberger (1955, p. 325). Fossil brachiopods from the formation include: *Ambocoelia umbonata*, *Atrypa spinosa*, several species of *Camarotoechia*, of *Productella*, and of "*Spirifer*", and among the pelecypods in the Chemung are several species of *Aviculopecten* and of *Leptodesma* (Butts, 1940, pp. 329-332). The formation is correlated with the Chemung formation of New York, Pennsylvania, and West Virginia.

HAMPSHIRE (CATSKILL) FORMATION

Name and distribution—The Hampshire formation was named by Darton (1892) from Hampshire County, West Virginia. The Hampshire is called Catskill formation on the Geologic Map of the Appalachian Valley in Virginia (Butts, 1933). However, Butts (1940, p. 333) said: "It has recently been demonstrated that the Catskill formation of the type locality in the Catskill Mountains of eastern New York corresponds mainly to the Hamilton and Portage formations, and that the Chemung and Hampshire formations are younger than the true Catskill." (See Chadwick, 1933, pp. 86-87; 1936). Woodward (1943) considered the Catskill to be a continental "red-bed" facies of the Hampshire and other marine Devonian formations as far down as the Hamilton. The Hampshire is extensively exposed in the western part of Rockingham County and is at the surface along most of the western border of the county. Good exposures of the formation occur along Long Run road west of Hopkins Gap in Little North Mountain, along old and new U. S. Highway 33 west of Rawley Springs, and along State road 924 west of Briery Branch.

Character and thickness—The most distinctive characteristic of the Hampshire is the red color although some of the beds are greenish or brownish. The formation consists principally of fairly thick-bedded arkosic and micaceous sandstone with some shale and lumpy mudrock. Beds of thin-bedded sandstone or "flagstone" are common in places. The sandstones of the Hampshire commonly are cross-bedded, and have various features which probably resulted, at least in part, from scour and fill. Along U. S. Highway 33 in West Virginia, adjacent to Rockingham County, the thickness of the Hampshire is about 2000 feet (Butts, 1940, p. 335). Young and Harnsberger (1955, p. 323) gave an approximate thickness of 2000 feet for the formation in the Bergton area. The thickness of the Hampshire about a mile and a half west of Briery Branch is about 2000 feet.

Fossils and correlation—Fossils occur in the Hampshire formation in Pennsylvania, but Butts (1940, p. 335) said: "No fossils have been found in the Hampshire in Virginia." Young and Harnsberger (1955, p. 335) reported that in the Hampshire beds west of Bergton, they found marine fossil zones containing poorly preserved brachiopods and pelecypods that resemble elements of the Chemung fauna. The absence of identifiable fossils makes correlation with other areas difficult. The Hampshire is the same as the old Catskill formation of Virginia, West Virginia, and Maryland.

MISSISSIPPIAN SYSTEM

POCONO FORMATION

Name and distribution—The Pocono formation was named by Lesley (1876) from Pocono Mountain in eastern Pennsylvania. The Pocono commonly is known as the Price formation in southwestern Virginia and Tennessee, but the name Pocono has priority. In Rockingham County the principal occurrence of the Pocono is in a synclinal belt approximately 2 miles wide, extending from the Augusta County line southwest of Briery Branch to about 4 miles northeast of Rawley Springs. The formation also occurs on the top of a number of high knobs in the southwestern part of Rockingham County. Good exposures of the Pocono occur at and near Rawley Springs.

Character and thickness—In the county the Pocono consists principally of massive, well-indurated, white to gray thick-bedded sandstones and interbedded dark shales. The full thickness of the formation does not appear to be present in Rockingham County but thin impure coal beds that occur near Rawley Springs and to the southwest are indicative of the upper part of the Pocono. In areas outside of Rockingham County the formation contains much shale. The formation apparently varies considerably in thickness. Butts (1940, p. 347) reported a thickness for the Pocono (Price) of about 300 feet in Wise County and of about 360 feet near Bluefield, Virginia. The formation is about 1700 feet thick in Montgomery County and about 600 feet thick in parts of Bland and Smyth counties (Campbell, 1925, p. 24). Because of lack of a complete section, no estimate can be made for the thickness of the formation in Rockingham County.

Fossils and correlation—The fossil content of the Pocono (Price) includes bryozoans, brachiopods, pelecypods, gastropods, and other types (Butts, 1940, pp. 348-350). According to Woodward (1943) no marine fossils have been found in the formation in West Virginia but plant remains are abundant in places. The Pocono correlates with the Price of southwest Virginia and Tennessee and probably with the Cuyahoga formation of Ohio (Butts, 1940, pp. 347-350).

TRIASSIC SYSTEM

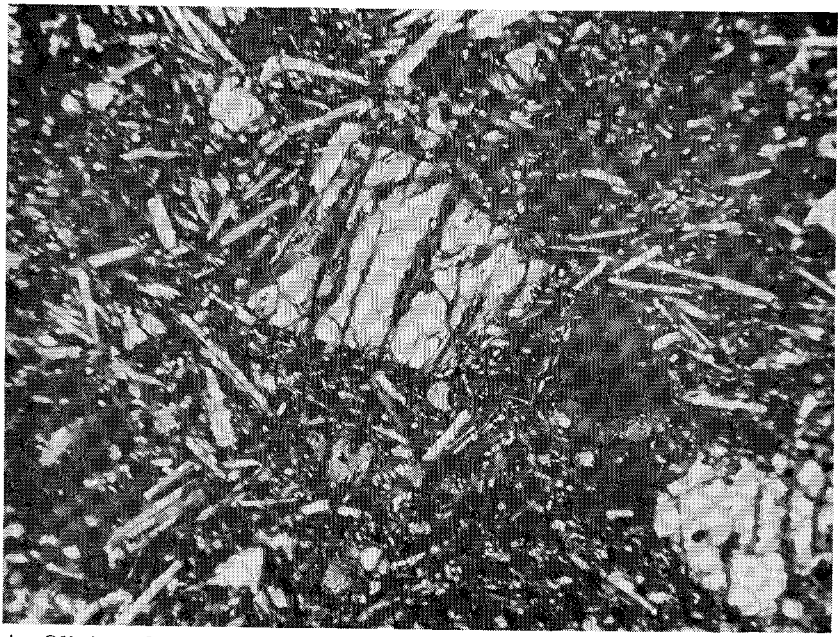
INTRUSIVE IGNEOUS ROCKS

The igneous intrusives of Triassic (?) age in Rockingham County consist of one plug, Mole Hill, about eleven or twelve dikes, and at least one sill or sill-like body.

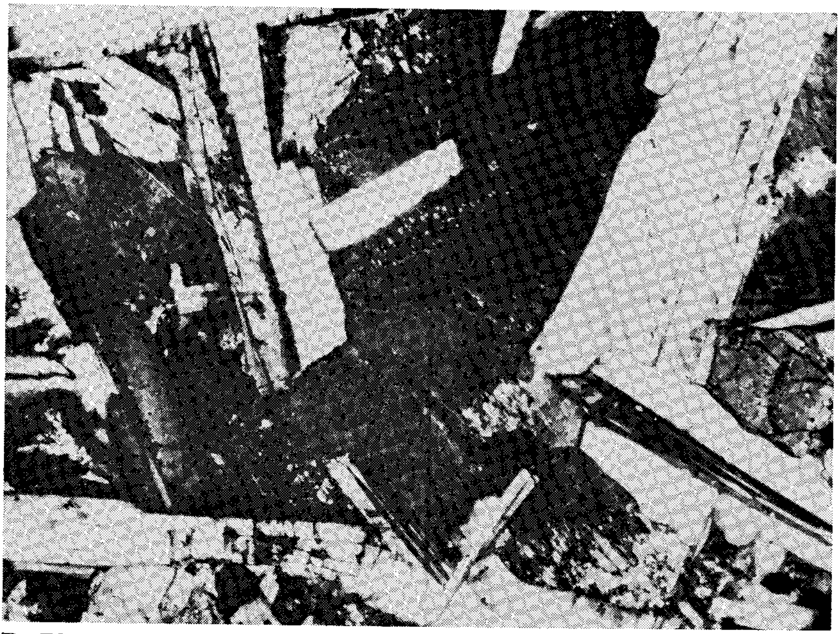
MOLE HILL

Mole Hill, about 4 miles west of Harrisonburg, is a conspicuous topographic feature about 500 feet high which rises abruptly from near the center of a wide area of undulating Beekmantown dolomite (Pl. 17A.) At the base, the hill extends slightly more than one-half mile in an east-west direction and a little less than one-half mile in a north-south direction. Around the western border of the hill gentle dips in the Beekman-

Plate 12

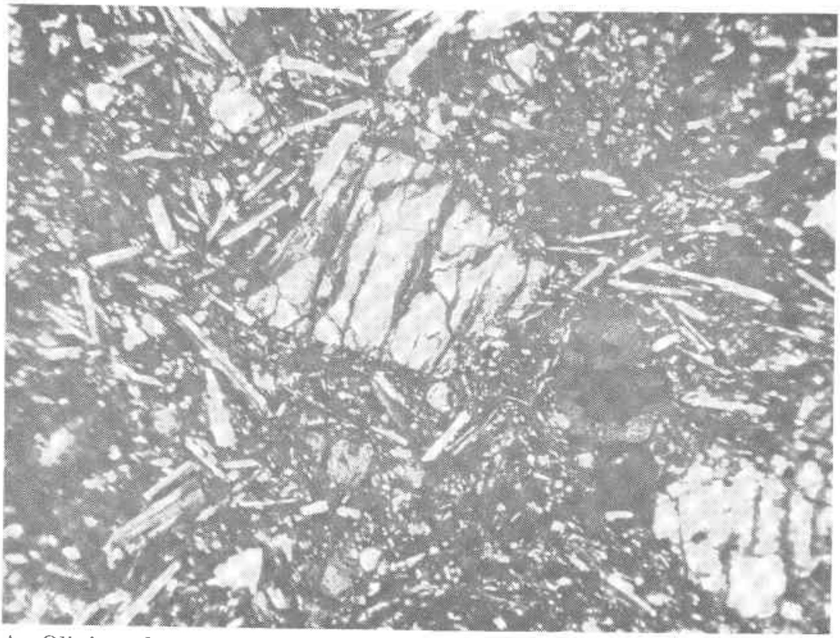


A. Olivine phenocrysts in olivine basalt of Mole Hill about 4 miles west of Harrisonburg. Photomicrograph by R. S. Young. x30.

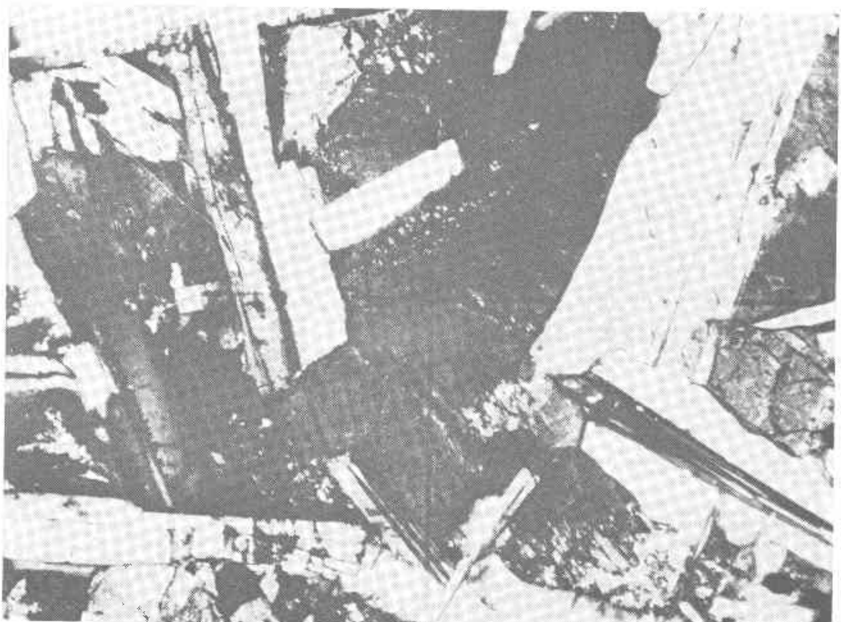


B. Photomicrograph of olivine diabase from dike near Grottoes. Note intergrowth of labradorite and augite. x100.

Plate 12

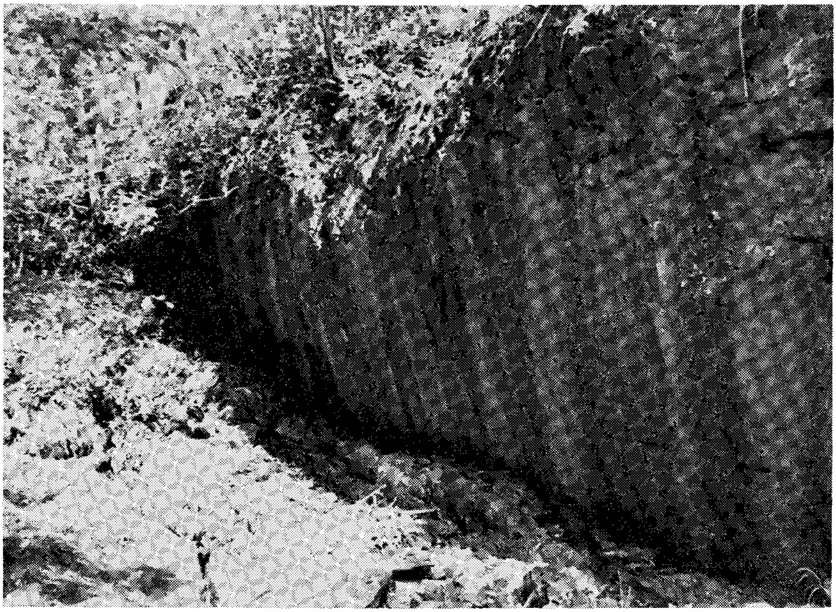


A. Olivine phenocrysts in olivine basalt of Mole Hill about 4 miles west of Harrisonburg. Photomicrograph by R. S. Young. x30.



B. Photomicrograph of olivine diabase from dike near Grottoes. Note intergrowth of labradorite and augite. x100.

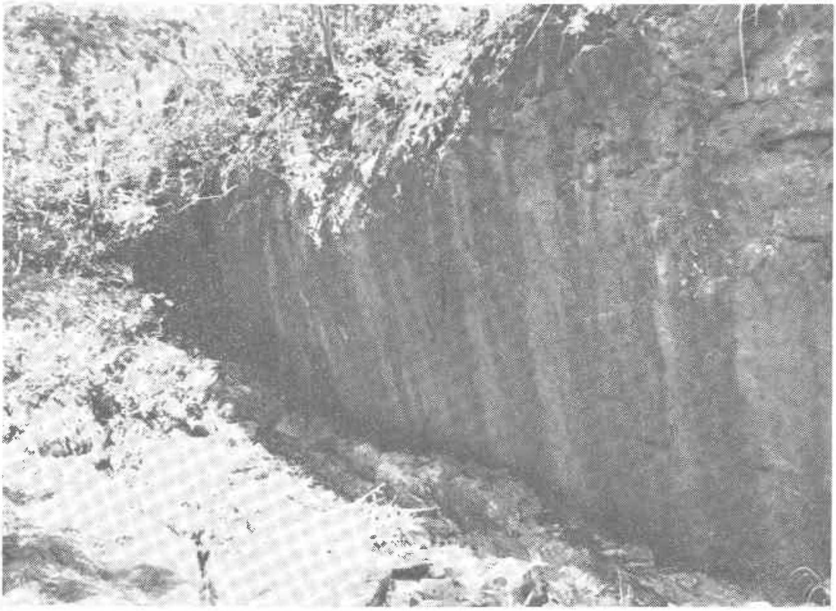
Plate 13



A. Little North Mountain fault about 0.5 mile southwest of Cootes Store. Conococheague limestone on right, Edinburg formation on left. Fault dips 70° S. E. Note hammer across fault near lower center of photograph.

B. Cliff at north end of Burketown klippe about 0.5 mile west of Mt. Crawford. Photograph by R. S. Young.

Plate 13



A. Little North Mountain fault about 0.5 mile southwest of Cootes Store. Conococheague limestone on right, Edinburg formation on left. Fault dips 70° S. E. Note hammer across fault near lower center of photograph.

B. Cliff at north end of Burketown klippe about 0.5 mile west of Mt. Crawford. Photograph by R. S. Young.

town indicate that the plug may occupy a structural depression. Outcrops around the eastern half are not common except directly to the east of the plug, and here there seems to have been minor shearing and reliable dips cannot be obtained.

The contact of the igneous and sedimentary rocks is not exposed because of weathering and cover. Rock fragments of the plug are abundant on the top and on all sides of the hill, and regardless of size almost every piece is angular. Some fairly large pieces show well-developed columnar jointing, and the angularity of the small pieces apparently results from this original structure (Pl. 11A).

Megascopically the plug consists of dark green to black porphyritic rock. As seen in thin section the minerals present are: labradorite, augite, olivine, magnetite, serpentine, chlorite, carbonate, and possibly a little epidote. The rock is classified here as an olivine basalt.

The labradorite occurs as small laths that commonly show a fair degree of alignment (Pl. 11B). Augite has two modes of occurrence, as groundmass and as phenocrysts. The augite in the groundmass consists of small green crystals, but the phenocrysts are colorless and may or may not have inclusions of plagioclase, magnetite, and olivine. Olivine occurs as phenocrysts of various sizes and is commonly little altered (Pl. 12A). Where present, alteration products are commonly serpentine, chlorite, and magnetite. Rarely a carbonate rhomb is enclosed within an olivine phenocryst, and in places iron-oxide stains occur along cracks in olivine. Scattered grains of magnetite are abundant throughout the rock.

DIKES AND SILLS

The longest dike in the county has almost continuous outcrops or numerous loose rounded boulders marking its location for about 5 miles, but it has no definite topographic expression. It trends a little west of north and extends from about 1.5 miles northwest of Park View to just northeast of Singers Glen. The width is variable and difficult to measure, but in places the dike appears to be 50 feet or more wide. One dike, with discontinuous exposures for about 2.5 miles, occurs just east of Harrisonburg, and another dike, of about the same length, trends northwest from the western edge of Grottoes. A number of smaller dikes, generally less than a mile long, occur at scattered localities. There is an exposure of dike rock along a bend in State road 784, ¼ mile northeast of Tide Spring, that is not indicated on the geologic map because of accidental omission. This dike, which is within the Beekmantown dolomite, appears to have a north or a north-northwest strike, but the extent of the dike is not known. A sill or sill-like body, about 2.5 miles long, extends in a northeasterly direction from just east of Greenwood to just southwest of the town of Shenandoah, Page County. Along Humes Run the igneous rock clearly can be seen to be interlayered with the nearly vertical dolomite beds of the Beekmantown and at this locality the igneous body is about 29 feet wide. Although the relationships at the surface are those of a sill, it is possible that at depth the igneous body has cross-cutting relations with the intruded rock. There are smaller igneous bodies in the county which strike parallel to the enclosing sedimentary rock, but outcrops are so poor that it could not be determined if the relations are those of a sill or a dike.

Megascopically the dike and sill rock is dark colored, medium textured, and commonly contains phenocrysts. One thin section from the dike northwest of Grottoes (Pl. 12B) was examined and found to be olivine diabase and it is assumed that the other dikes probably are similar lithologically. The minerals present are: labradorite, augite, olivine, magnetite, serpentine, chlorite, and biotite. Interpenetrating labradorite laths and augite give the rock a diabasic or ophitic texture. Olivine phenocrysts and small magnetite crystals are scattered throughout the rock. There is relatively little alteration, but in places magnetite has formed from augite, and serpentine, chlorite, and magnetite have developed at the expense of olivine. A few strongly pleochroic red-brown biotite shreds are present.

The intrusives in this area are probably of the same character, origin and age as similar intrusives that cut Paleozoic rocks in other parts of the Valley of Virginia. In Rockingham County the youngest rocks known to the writer that have been cut by these intrusives are of Ordovician age. These intrusive rocks probably were intruded during the Triassic period (Butts, 1940, p. 435).

Geologic Section 1—About 1 mile north-northeast of Trissel Church

Beekmantown dolomite

	Chepultepec limestone (lower part, 266 feet) strike N. 20° E.; dip 28° S. E.	Thickness Feet
36	Covered area, contact with Beekmantown uncertain	
35	Limestone, blue; black chert	1
34	Limestone, blue	14
33	Dolomite	3
32	Limestone, blue; some chert, some gastropods and cephalopods	9
31	Limestone, blue, massive, some chert	34
30	Limestone, blue; some chert, clay partings	19
29	Limestone, blue, massive	2
28	Limestone, blue, clay partings, chert, small gastropods	34
27	Limestone, gray, chert, clay partings	4
26	Covered interval	1
25	Limestone, blue, black nodular chert	8
24	Limestone, gray, fine-grained	1
23	Limestone, blue, medium-grained	2
22	Limestone, blue, thin-bedded	6
21	Dolomite, dark, coarse-grained	1
20	Limestone, blue	3
19	Limestone, gray, fine-grained, some chert	4
18	Limestone, blue, clay partings, some chert	12
17	Limestone, gray, fine-grained, small gastropods	2
16	Limestone, blue, clay partings	14
15	Limestone, blue, fossiliferous	2
14	Limestone, blue, clay partings, thin-weathering	21
13	Limestone, blue, clay partings	20
12	Limestone, blue, black chert	9
11	Limestone, blue, thin-dolomite layers, chert	1
10	Dolomite, gray	5
9	Limestone, blue, thin dolomite layers, clay partings, chert	5
8	Limestone, gray, fine-grained	2
7	Dolomite, gray, sugary-grained	4
6	Dolomite, dark, coarse-grained	1
5	Dolomite, dark, medium-grained, dark chert	9
4	Covered interval	8
3	Dolomite, dark, coarse-grained	1
2	Limestone, blue, black chert	4
1	Covered area, lower contact uncertain	

Conococheague limestone

Geologic Section 2—About 1.5 miles east of Singers Glen, strike N. 35° E.; dip varies from 5° S. E. to 30° S. E. (average dip about 17° S. E.)

New Market Limestone

	Beekmantown dolomite (upper 1222 feet)	Thickness Feet
83	Dolomite, gray, fine-grained	1
82	Covered interval	2
81	Limestone, blue	2
80	Limestone, dove-gray, some intraformational conglomerate	4
79	Dolomite	1
78	Limestone, dove-gray	1
77	Dolomite, gray, fine-grained	14
76	Dolomite, dark gray, medium-coarse-grained	5
75	Dolomite, gray, fine-grained	18
74	Dolomite, dark, medium-coarse-grained	2
73	Dolomite, gray, fine-grained	4
72	Dolomite, light gray, medium-coarse-grained	13
71	Dolomite, gray	33
70	Dolomite, gray, medium-coarse-grained	19
69	Dolomite, dark, sugary-textured	1
68	Dolomite, gray, medium-grained	11
67	Dolomite, gray, some pinkish	3
66	Dolomite, light gray, fine-grained	33
65	Dolomite, light gray, medium-fine-grained	7
64	Covered interval	8
63	Dolomite, dark gray, sugary textured	3
62	Dolomite, light gray, sugary, pitted	1
61	Dolomite, gray	10
60	Dolomite, dark, sugary textured, fractured	2
59	Dolomite, dark	4
58	Dolomite, dark, sugary textured, white calcite veins, vugs	2
57	Dolomite, gray	12
56	Dolomite, dark	4
55	Dolomite, gray, some shale and chert	11
54	Dolomite, gray	7
53	Dolomite, light gray, sugary-textured, mottled	3
52	Dolomite, dark, sugary-textured, chert, vugs, irregular lenses of compact, dove-gray limestone up to 4 feet thick	14
51	Dolomite, gray	66
50	Dolomite	13
49	Dolomite, dark, sugary	5
48	Dolomite, dark	4
47	Dolomite, gray, vugs	33
46	Dolomite, gray, fractured	16
45	Dolomite, dark	17
44	Dolomite, gray, some fractured	33
43	Dolomite, with massive chert	33

		Thickness Feet
42	Dolomite, gray	65
41	Dolomite, gray, massive chert and porous chert	100
40	Covered interval	70
39	Dolomite, gray, massive and porous chert	165
38	Dolomite, gray	70
37	Dolomite, crumpled, some weathers thin-bedded	10
36	Dolomite	30
35	Limestone, blue, clay partings	3
34	Dolomite, thin-bedded	2
33	Dolomite, gray, fine-grained	14
32	Dolomite, gray	16
31	Dolomite, bluish	2
30	Dolomite, gray	7
29	Dolomite, dark, medium-grained, some chert	8
28	Dolomite, gray, fine-grained	34
27	Covered interval	4
26	Dolomite	12
25	Covered interval	10
24	Dolomite	9
23	Covered interval, chert in soil	20
22	Dolomite, dark, sugary grained, small black chert	5
21	Covered interval	3
20	Dolomite, gray	5
19	Covered interval	9
18	Dolomite, gray, with some chert pieces	3
17	Covered interval	6
16	Dolomite	1
15	Covered interval	4
14	Dolomite	2
13	Covered interval	4
12	Dolomite	1
11	Covered interval	4
10	Dolomite, dark, some porous chert	17
9	Dolomite, light gray, fine-grained	3
8	Covered interval	3
7	Dolomite, dark, medium-coarse grained	1
6	Covered interval	2
5	Dolomite	2
4	Covered interval	5
3	Dolomite, dark, cherty	5
2	Covered interval	2
1	Dolomite, gray	9
	Covered area	

Chepultepec limestone

Geologic Section 3—Vicinity of Elkton Lime and Stone Company quarry, 3 miles northwest of Elkton. (After Edmundson, 1945, pp. 131-134)

Beekmantown formation (upper part, 1,202 feet)		Thickness Feet
88	Limestone, dark gray, magnesian, fine-grained	5
87	Limestone, bluish-gray, fine-grained	3
86	Limestone, mottled light and dark gray, magnesian	18
85	Limestone, bluish-gray, compact	3
84	Dolomite, gray, fine-grained	1
83	Limestone, mottled light and dark gray, magnesian	3
82	Limestone, bluish-gray, compact	2
81	Dolomite, gray, fine-grained	2
80	Limestone, bluish-gray, compact	3
79	Dolomite, light gray	1
78	Limestone, mottled light and dark gray, magnesian	3
77	Limestone, bluish-gray, compact	1
76	Dolomite, gray	5
75	Limestone, dark gray, magnesian	1
74	Dolomite, dark gray, fine-grained	2
73	Limestone, bluish-gray, compact; 6 inch clay zone at base	3
72	Limestone, mottled light and dark gray, magnesian	15
71	Limestone and dolomite, banded; light bands dolomite; dark bands limestone	7
70	Dolomite, gray, fine-grained	1
69	Dolomite, fine-grained; weathers drab-gray; 2-inch shale bed at top	13
68	Limestone, dark gray, fine-grained	5
67	Dolomite, greenish-gray, fine-grained	2
66	Limestone, bluish-gray, compact	1
65	Limestone, mottled light and dark gray, magnesian	3
64	Dolomite, gray, fine-grained	3
63	Limestone, mottled light and dark gray, magnesian	5
62	Dolomite, dark gray	8
61	Limestone, dark gray, compact; a few layers of mottled magnesian limestone	12
60	Limestone, magnesian, banded	5
59	Limestone, mottled light and dark gray, magnesian	26
58	Limestone, magnesian	6
57	Limestone, mottled light and dark gray, magnesian	30
56	Dolomite, dark gray	5
55	Limestone, magnesian, banded	2
54	Limestone, mottled light and dark gray, magnesian	18
53	Limestone, magnesian	2
52	Dolomite, light gray, fine-grained	19
51	Dolomite, fine-grained; light and dark bands	43
50	Limestone, dark gray, magnesian	3
49	Dolomite, gray, fine-grained	8
48	Dolomite, medium-gray	6

		Thickness Feet
47	Dolomite, medium-gray; vugs of carbonate minerals; 2 inch shale bed at top	7
46	Limestone, dark gray, magnesian	1
45	Dolomite, light gray, fine-grained; weathers drab-gray	23
44	Limestone, gray, compact	4
43	Limestone, mottled light and dark gray, magnesian	2
42	Dolomite, gray, fine-grained	5
41	Limestone, mottled light and dark gray, magnesian	14
40	Limestone, bluish-gray, compact	5
39	Dolomite, dark gray	9
38	Limestone, mottled light and dark gray, magnesian	14
37	Dolomite, gray, fine-grained	25
36	Dolomite, light and dark gray, banded	34
35	Mostly covered; a few beds of light gray dolomite	23
34	Covered interval	37
33	Dolomite, gray, fine-grained	4
32	Limestone, bluish-gray, compact	11
31	Limestone, mottled light and dark gray, magnesian	8
30	Dolomite, light gray, fine-grained	3
29	Limestone, mottled light and dark gray, magnesian	13
28	Dolomite, gray, fine-grained	3
27	Limestone, bluish-gray, compact	7
26	Limestone, magnesian	5
25	Dolomite, gray, fine-grained	5
24	Limestone, bluish-gray	5
23	Dolomite, light gray	13
22	Limestone, mottled light and dark gray, magnesian	4
21	Dolomite, dark gray, fine-grained	22
20	Limestone, bluish-gray, compact	4
19	Limestone, mottled light and dark gray, magnesian	10
18	Dolomite, gray, fine-grained	22
17	Dolomite and banded blue limestone	14
16	Covered interval	37
15	Limestone, bluish-gray, compact	8
14	Dolomite, light gray, fine-grained	8
13	Limestone, mottled light and dark gray, magnesian	23
12	Dolomite, gray, fine-grained	13
11	Limestone and dolomite	45
10	Mostly covered; a few beds of gray dolomite	54
9	Dolomite, gray, fine-grained	40
8	Limestone, mottled light and dark gray, magnesian	5
7	Limestone and dolomite	70
6	Limestone, mottled light and dark gray, magnesian	32
5	Dolomite, gray, fine-grained	46
4	Limestone and dolomite	98
3	Limestone, bluish-gray	56
2	Dolomite, medium-gray, fine-grained	7
	Igneous intrusion	
1	Diabase (?) fine-grained, weathers dark brown	29

Geologic Section 4—About 4 miles southwest of Broadway, near Tide Spring.

		Thickness Feet
Edinburg formation (lower 20 feet)		
25	Limestone, dark, granular, fossiliferous, probably Botetourt member	20
Lincolnshire limestone (131 feet) strike N. 30° E.; dip 25° S. E.		
24	Limestone, dark, pink stains, bedded black chert	74
23	Limestone, dark, coarse, pink stains	12
22	Limestone, dark, medium-grained, bedded black chert	12
21	Limestone, dark bluish, medium-grained, red stains, cherty	33
New Market limestone (130 feet) strike N. 25° E.; dip 35° S. E.		
20	Calcilutite, gray, compact, clay partings	10
19	Limestone, dark blue, fine grained, red stains	8
18	Limestone, dark blue, clay partings	2
17	Calcilutite	4
16	Calcilutite, with *Tetradium*	12
15	Calcilutite, clay partings	1
14	Calcilutite, with *Tetradium*	13
13	Calcilutite, clay partings	12
12	Calcilutite	9
11	Calcilutite	8
10	Calcilutite, clay partings	2
9	Calcilutite, with *Tetradium*	2
8	Calcilutite, with clay partings	5
7	Calcilutite	23
6	Calcilutite	2
5	Calcilutite	2
4	Calcilutite, with *Tetradium*	4
3	Calcilutite, clay partings	4
2	Calcilutite, with *Tetradium*	4
1	Calcilutite	3
Beekmantown dolomite		

Geologic Section 5—About ¼ mile east of Broadway strike N. 10° E.; dip, 50° N. W.

		Thickness Feet
	Edinburg formation (lower 190 feet)	
27	Shale, calcareous, dark; thin limestone beds	135
26	Limestone, dark blue, thin bedded	10
25	Shale, calcareous, dark	8
24	Limestone, dark, shaly weathering, calcareous shale	30
23	Shale, calcareous, dark blue	7
	Lincolnshire limestone (146 feet)	
22	Limestone, dark, cobbly weathering, calcite stringers	25
21	Limestone, dark, coarse, similar to Botetourt member of Edinburg	10
20	Limestone, dark blue, bedded black chert, white calcite seams	37
19	Limestone, dark blue, cherty, thin bands of intraformational conglomerate and breccia	19
18	Limestone, dark blue, fine-grained, bedded chert, fossiliferous	2
17	Limestone, dark blue, fine-grained, bedded chert	17
16	Limestone, dark blue, medium-grained	3
15	Limestone, blue, bedded black chert	33
	New Market limestone (196 feet)	
14	Limestone, blue	10
13	Limestone	2
12	Calcilutite, intraformational conglomerate and breccia	2
11	Calcilutite, with *Tetradium*	42
10	Calcilutite	104
9	Calcilutite, with clay partings	5
8	Calcilutite	8
7	Calcilutite, with clay partings	2
6	Limestone, buff, intraformational breccia	1
5	Calcilutite, dove gray, with *Tetradium*	7
4	Limestone, buff, dense, brittle, calcite specks	2
3	Calcilutite, dove gray, with *Tetradium*	1
2	Limestone, light gray, fine-grained	1
1	Calcilutite, dove gray, with clay partings	9
	Beekmantown dolomite	

Geologic Section 6—About 2 miles east of Singers Glen
strike N. 50° E.; dip, 30° S. E.

Edinburg formation	Thickness Feet
7 Covered area	55
Lincolnshire limestone (lower 60 feet)	
6 Limestone, dark gray, granular, black chert, red stains on parting surfaces, white calcite veins	60
New Market limestone (151 feet)	
5 Limestone, gray, fine-grained, red stains on partings, grades upward into Lincolnshire	10
4 Limestone, dove gray, compact, with *Tetradium*	65
3 Calcilutite, dove gray, sheared, platy	25
2 Calcilutite, dove gray	23
1 Calcilutite, dove gray, some sheared and platy	28
Beekmantown dolomite	

Geologic Section 7—North side of North River, near Rockland Mill Church
strike N. 32° E.; dip, 55° S. E.

Edinburg formation	Thickness Feet
15 Covered area, shale chips in soil	100
Lincolnshire limestone (lower 43 feet)	
14 Limestone, dark blue, granular, pink clay partings, some sheared	16
13 Limestone, dark blue, granular, pink clay partings	27
New Market limestone (95 feet, approximately)	
12 Calcilutite, sheared	7
11 Calcilutite	4
10 Calcilutite, some sheared	3
9 Covered interval	32
8 Calcilutite, sheared	2
7 Covered interval	16
6 Limestone, gray and fine-grained	2
5 Covered interval	25
4 Limestone, blue, sheared	1
3 Covered interval	1
2 Limestone, blue	1
1 Calcilutite, sheared	1
Covered area at contact	
Beekmantown dolomite	

Geologic Section 8—Adjacent to U. S. Route 11, 2 miles south of Harrisonburg (After Cooper and Cooper, 1946, pp. 82-83)

		Thickness Feet
Reuschella "edsoni" zone		
Edinburg limestone (1,348 feet)		
Lantz Mills facies		
10	Limestone, cobbly, shaly; contains *Christiania* and *Resserella;* thin partings of granular limestone	25
9	Limestone, black, cobbly to slabby, contains *Nidulites pyriformis*	40
Liberty Hall limestone facies		
8	Limestone, dense, black, medium- to thin-bedded; many en echelon gash veins of white calcite	950
7	Limestone, dense, black, medium- to thick-bedded, with intercalated black graptolitiferous shales, not fully exposed	285
6	Shale, pinkish and flaky where weathered, black where fresh; contains graptolites	38
Botetourt limestone member		
5	Limestone, black, granular, contains *Bumastus, Bronteopsis,* and *Arthrorhachis*	10
Lincolnshire limestone (51 feet)		
4	Limestone, black, fine-grained, irregularly bedded, with reddish streaks along the bedding	12
3	Limestone, black, cherty, granular	39
New Market limestone (161 feet)		
2	Calcilutite, dove gray, medium-bedded, pure	83
1	Limestone, compact, light gray	78
Beekmantown dolomite		

Geologic Section 9—Along U. S. Highway 33, about 0.4 mile southeast of Peales (Massanutten) Crossroads
strike N. 30° E.; dip, 70° S. E.

		Thickness Feet
Martinsburg shale		
*Edinburg formation (partial section of 274+ feet)		
15	Shale, black and gray, thin fissile, weathers gray, contains thin shaly limestone beds, upper contact not located	50+
14	Shale, dark blue, contains graptolites; thin limestone bands	8
13	Limestone and shale	1
12	Shale, contains graptolites; thin limestone	17
11	Limestone, blue-gray, some platy, some several inches thick; shale partings with graptolites	27

		Thickness Feet
10	Shale, black, calcite seams parallel to bedding	1
9	Limestone, bluish-gray, thin and banded, shale partings with graptolites	60
8	Shale, with thin limestone with many fossil fragments	17
7	Shale, blue, and thin limestone	7
6	Limestone, black	1
5	Shale, black, calcareous, with thin limestone	17
4	Limestone, shaly	1
3	Shale, calcareous, weathers banded	21
2	Mostly covered, shale exposures	27
1	Shale, calcareous, black, with thin limestone, lower contact largely covered	19

Lincolnshire limestone

---

*Fossils from this area identified by Cooper and Cooper (1946, p. 99) include: *Robergia*, *Cryptolithus*, *Diplograptus*, *Climacograptus*, and *Dicellograptus*.

Geologic Section 10—About 1.6 miles south of Bethel Church and 6 miles east of Harrisonburg (After Cooper and Cooper, 1946, p. 97).

Martinsburg formation (contact approximate)

Edinburg formation (all Liberty Hall facies, 943 feet)

		Thickness Feet
11	Shale and limestone, black	210
10	Siltstone, rusty brown, friable; contains *Parastrophina* sp.	35
9	Limestone, dense, black, weathers bluish-gray; contains trilobites	225
8	Limestone, thin-bedded, shaly; graptolites	142
7	Limestone, black, medium-bedded, very little shale	70
6	Limestone, contains *Ptychoglyptus*, *Multicostella* cf. M. *bursa*, trinucleid trilobites	61
5	Shale, black with graptolites; contains intercalated platy black limestones	150
4	Limestone, thin-bedded to platy, black; contains trilobites	30
3	Botetourt limestone member, brownish weathering, coarse-grained, makes crest of ridge; contains "*Leptobolus ovalis*" Bassler	20

Lincolnshire limestone (40 feet)

2	Limestone, dark bluish-gray, cherty	40

New Market limestone (65 feet)

1	Calcilutite, medium- to thick-bedded; dove gray to black	65

Beekmantown dolomite

Geologic Section 11—South end of Cooper Mountain	Thickness
Clinch sandstone (?) (45 feet approximately) strike N. 30° E.; dip, 70° S. E. (overturned)	Feet
12 Sandstone, white, silica cement, mostly massive and thick-bedded, some minor faulting; shear at base, dips 60° N. W., drag indicates northwest block moved to southeast	45
Oswego-Juniata (643 feet) Probably all Oswego strike N. 30°-40° E.; dip, 90° to 70° S. E. (overturned)	
11 Sandstone, gray, mostly thick-bedded and massive	12
10 Covered interval	40
9 Sandstone, bluish-gray, mostly thick-bedded and massive	54
8 Sandstone, bluish-gray, massive, some small faults	50
7 Sandstone, bluish-gray, thick-bedded, some cross-bedding	50
6 Sandstone, bluish-gray, thick-bedded, some iron speckled dense sandstone	215
5 Sandstone, thick-bedded, dense, some iron-speckled	50
4 Sandstone, gray, dense, blocky, rectangular weathering, some thin-bedded shaly sandstone	32
3 Sandstone, brown and green, dense, some iron-specks	65
2 Sandstone, brown and green, dense, some iron-specks, some shaly zones, lower contact indefinite	75
Martinsburg shale (upper 50+ feet)	
1 Sandstone, gray and greenish, resembles *Orthorhynchula* beds but no fossils found	50+

Geologic Section 12—Hopkins Gap in Little North Mountain
Generally poor exposures, contacts covered

Ridgeley sandstone (50 feet (?))	Thickness Feet
12 Covered area, Ridgeley float	50(?)
Helderberg group (175 feet (?))	
11 Limestone, bedded black chert, contacts covered	175(?)
10 Covered area, possibly Cayuga group	100 (?)
Clinton formation (240+ feet)	
9 Covered area, iron oxide and shale float, contact obscure	100
8 Sandstone, white to gray, dense, some massive beds 2 feet thick, possibly Keefer member	32
7 Iron oxide, possibly limonite	4
6 Sandstone, white and red, some iron oxide	54
5 Sandstone, white and red, some iron oxide, lower contact obscure	50

		Thickness Feet
Clinch sandstone (130 feet, approximately) strike N. 45° E.; dip, 65° S. E.		
4	Covered area, sandstone float, possibly Clinch	33
3	Sandstone, dense, silica cement, some medium-grained	86
2	Conglomerate, white quartz pebbles up to ½ inch, white sandstone, silica cement	11
Oswego-Juniata (430 feet, approximately)		
1	Sandstone, crumbly, iron-speckled, lower contact obscure, probably mostly Oswego sandstone	430
Martinsburg shale		

Geologic Section 13—Brocks Gap in Little North Mountain
Covered area, probably Juniata

		Thickness Feet
Oswego sandstone (370+ feet*) strike N. 35° E.; dip, overturned, 60° to 80° S. E.		
21	Sandstone, gray, dense	71
20	Sandstone, massive, cross-bedded, clay pellets, some thin shale partings	14
19	Sandstone, gray, massive	14
18	Sandstone, gray and green, thin shale partings	15
17	Sandstone, green	1
16	Sandstone, reddish and greenish	11
15	Shale, silty	1
14	Sandstone, greenish and gray	14
13	Sandstone, greenish and gray, bedding obscure (possible internal folding)	71
12	Sandstone, green and gray	27
11	Shale and thin sandstone	1
10	Sandstone, gray	67
9	Sandstone, gray and green, thin shale	14
8	Shale, thin, and thin sandstone, greenish, interbedded	5
7	Sandstone, green, with clay pellets	4
6	Shale, green	1
5	Sandstone and shale, gray and green, interbedded	8
4	Sandstone, light gray	4
3	Sandstone, gray, thin shale	6
2	Sandstone, thin green shale	21
Fault—2 northwest dipping reverse faults with wedge of fossiliferous *Orthorhynchula* beds between the faults.		
1	Martinsburg shale, Orthorhynchula zone	

*Below fault, 80 feet or so of Oswego in vertical cliff. Oswego possibly 450 feet thick.

Geologic Section 14—Brocks Gap in Little North Mountain

		Thickness Feet
Ridgeley sandstone (55 feet) strike N. 30° E.; dip, 90°		
10	Sandstone, calcareous, abundant fossils, approximately 10 foot transition zone with underlying Helderberg	55
Helderberg group (possibly 450 feet thick)		
9	Limestone, fossiliferous, bedded black chert, about	300
8	Covered interval, some shale toward lower part, about	150
Cayuga group (possibly 225 feet thick)		
7	Covered interval, some thinly-laminated limestone, probably Tonoloway limestone	225
Clinton formation (270 feet)		
6	Sandstone, red, ironstone, crumbly yellow sandstone at or near upper contact	270
Clinch sandstone (53 feet)		
5	Sandstone with silica cement, white and gray quartz pebble conglomerate especially toward base	53
Juniata formation (212 feet)		
4	Sandstone, dark, thin-bedded	2
3	Sandstone, gray, massive	2
2	Sandstone, mudrock, shale, red and green	18
1	Covered interval, probably Juniata	190
Oswego sandstone		

Geologic Section 15—Little North Mountain, about 1 mile south of Shenandoah County line

Millboro-Onondaga

		Thickness Feet
Ridgeley sandstone (140 feet) strike N. 40° E.; dip, 90°		
1	Sandstone, many large brachiopods, lower contact covered	140

Geologic Section 16—Little North Mountain, about 1 mile south of Shenandoah County line

Clinton formation (lower 94 feet)	Thickness Feet
8 Covered area	
7 Shale, red and green, iron ore, probably hematite, some thin sandstone	20
6 Sandstone, some shale	11
5 Sandstone, red, some massive 6-inch thick layers	6
4 Sandstone, red and green, some iron ore, probably hematite	43
3 Sandstone, red, shale, some limonitic sandstone	14
Clinch sandstone (75 feet, approximately)	
2 Sandstone, white, dense, some quartz pebble conglomerate, lower contact indefinite	75
Oswego-Juniata (200 feet, approximately)	
1 Sandstone, gray, some iron-specks, contacts indefinite	200
Martinsburg shale	

Geologic Section 17—Fridley Gap in Massanutten Mountain

Massanutten sandstone (lower part, 529 feet) strike N. 35° E.; dip, 40° S. E.	Thickness Feet
4 Sandstone, white, massive, silica cement	74
3 Covered interval, probably massive white sandstone with silica cement	56
2 Sandstone, white, massive, silica cement, some quartz pebble conglomerate, some yellow sandstone, some cross-bedding, lower contact not exposed	399
Martinsburg shale (upper 100 feet)	
1 Sandstone, dark greenish, iron speckled, some shale, upper contact not exposed	100 ±

Geologic Section 18—Runkles (Ruckles) Gap in Massanutten Mountain

		Thickness Feet
	Cayuga group, Bloomsburg formation (lower 74 feet) strike N. 30° E.; dip, 90°	
	Covered area	
22	Sandstone, red, shaly weathering, some clay ironstone	28
21	Sandstone, red and white; both thick and thin beds	18
20	Sandstone, white, thick-bedded, some shaly weathering	21
19	Sandstone, yellowish, massive	1
18	Sandstone, thin-bedded, shaly	4
17	Sandstone, dense, lenticular, some thin-bedded	2
	Massanutten sandstone (646 feet) strike N. 30° E. to N. 40° E.; dip, 90° to 75° S. E. (overturned)	
16	Sandstone, dense, some lenticular thin-bedded, shaly sandstone	5
15	Sandstone, thin-bedded, shaly	2
14	Sandstone, white, silica cement	38
13	Sandstone, yellowish, dense	5
12	Sandstone, white, silica cement	38
11	Sandstone, white and yellow, dense, some conglomerate, some cross-bedding	100
10	Sandstone, white and yellow, silica cement	49
9	Conglomerate, white, quartz pebble	7
8	Conglomerate, white, small quartz pebbles	25
7	Sandstone, white, silica cement	72
6	Sandstone, white and yellow, some cross-bedding	88
5	Sandstone, white, dense	60
4	Sandstone, white, beds more than 1 foot thick	58
3	Sandstone, white, dense, beds about 1 foot thick	48
2	Sandstone, white, dense, thick-bedded	51
	Martinsburg shale (upper 100 feet)	
1	Sandstone, greenish, fine-grained, some shale	100 ±

STRUCTURE

Rockingham County contains four northeast trending structural areas that include, from southeast to northwest: the Precambrian rocks and northwest dipping Lower Cambrian sedimentary rocks of the Blue Ridge; the folded and thrust-faulted Middle and Upper Cambrian and Ordovician sedimentary rocks of the Shenandoah Valley and the Massanutten synclinal complex that contains rocks younger than the Ordovician; the Little North Mountain fault zone and the mainly steeply dipping to overturned Upper Ordovician, Silurian, and Lower Devonian sedimentary rocks of Little North Mountain; and the folded Devonian and Mississippian sedimentary rocks that occupy the area between Little North Mountain and Shenandoah Mountain, the crest of which forms the Virginia-West Virginia boundary. In this area some older rocks, Silurian and Ordovician, are exposed in one anticline.

EASTERN PART OF COUNTY

PRECAMBRIAN STRUCTURAL FEATURES

Although the Precambrian rocks were deformed along with the younger rocks in the Appalachians during the late Paleozoic, they have structures not found in the younger rocks and these are probably of Precambrian age. King (1950, p. 39), found a gneissic structure with a low dip and variable strike in the Virginia Blue Ridge complex (injection complex) which seems to be truncated by an unconformity at the base of the Swift Run formation. No detailed study has been made of the Precambrian rocks in Rockingham County.

The contact between the Chilhowee group and the underlying rocks occurs as a single line well up on the west side of the Blue Ridge. This contact and the relations between the two groups of rocks are not well known. In the Shenandoah salient, north of Rockingham County and east of the town of Shenandoah, Page County, the contact at the base of the Chilhowee is exposed at a number of places. In this salient, the Catoctin greenstone, the Swift Run formation, and the Virginia Blue Ridge complex (injection complex) are overlain by the Chilhowee group (King, 1950, pp. 39-40). These relations were described by King (1950, p. 41) as follows: "The northwestward truncation of the Catoctin greenstone and Swift Run formation, and the southeastward thickening of the Catoctin are interpreted as being due largely to tilting before Cambrian time and to erosion before the Chilhowee group was deposited."

In the main area of the Blue Ridge the Catoctin has a more strongly developed slaty cleavage than do the sedimentary rocks to the northwest. In the Shenandoah Salient, no major difference in the degree of metamorphism of the Catoctin and that of the overlying Chilhowee rocks has been found (King, 1950, p. 41).

LATE PALEOZOIC STRUCTURAL FEATURES

The area between the Cambrian or Precambrian rocks of the Blue Ridge and the South Fork of the Shenandoah River is occupied principally by northwest dipping Cambrian age sedimentary rocks. In their easternmost areas of exposure, the Lower Cambrian rocks have a gentle northwesterly dip. In the Valley proper, farther to the northwest, the Middle and Upper Cambrian rocks dip steeply to the northwest or are overturned and have steep southeast dips. There are, of course, many exceptions to this general description and in places the Lower Cambrian rocks dip steeply and in other areas folds may be observed in the Cambrian rocks. The metamorphism of the Lower Cambrian rocks is greater than that of the average for other Paleozoic rocks of the Appalachian Valley. Many of the shales have been changed to phyllite and the effects of flowage are visible in some of the limestones and dolomites. Faults are present but they are not a dominant type of structure and there are no large overthrusts.

ELKTON EMBAYMENT

Northeast of Elkton in the re-entrant in the Blue Ridge known as the Elkton embayment, the Shady (Tomstown) and Rome (Waynesboro) formations and perhaps other Valley-type rocks are covered by Quaternary gravels. The structure within the embayment is unknown because of the gravel cover, but the embayment is the result of a downwarp (King, 1950, p. 44). In the Shenandoah salient, north of Rockingham County, folds in the Erwin (Antietam) plunge to the southwest toward the embayment. On the southwest side of the embayment, folds in the Erwin plunge to the northeast but the structure is complicated by faulting.

The narrow outcrop of the Chilhowee group southeast of the embayment probably results from omission of beds by the northeast trending Huckleberry Mountain fault. In places it apparently dips steeply to the southeast and is thought to be a reverse fault. Near the southeastern end of the fault the lower Weverton member is found on the east side of the fault and is against the Hampton (Harpers) formation and the Erwin quartzite. Between the fault and the gravel cover to the northwest, there are several narrow folds involving principally the Hampton formation and Erwin quartzite.

In the zone of west-northwest trending faults that marks the southwestern boundary of the Elkton embayment, the rocks on the south side of the fault have been moved westward (King, 1950, p. 44). In places within the fault zone, bedding is obscure, quartzite is broken and shattered, and iron oxide fills the fractures. The Huckleberry Mountain fault apparently ends in this zone of west-northwest trending faults.

SOUTHWEST OF THE ELKTON EMBAYMENT

Southwest of the Elkton embayment the Chilhowee rocks crop out as much as 2 miles farther northwest than they do in the embayment and maintain this relative position to the southwest to the Augusta County line. A short distance southwest of the Elkton embayment and on the southwest side of Swift Run (creek), the north-northwest trending Swift Run fault extends for several miles roughly parallel to and on the southwest side of U. S. Highway 33. Regarding this fault, King (1950, p. 45) wrote: "No brecciated rock was seen near it and its presence is indicated mainly by discontinuities between the outcrops on opposite sides of the valley of Swift Run. Movements along it are apparently nearly vertical; it may be a normal fault, downthrown to the west. In most places it lies in northwest dipping beds whose outcrops on the east side are offset northward relative to those on the west side."

In the area just southwest of Swift Run there are several open folds in the Chilhowee group rocks. One anticlinal axis follows the crest of Hanse Mountain, which has northwest and southeast dip slopes of Erwin quartzite. West of Hanse Mountain is a conspicuous hill, Giants Grave, which is a doubly plunging anticline of Erwin quartzite. Farther to the southwest the Chilhowee rocks are folded into a number of anticlines and synclines in which the dips are generally less than 45°.

The area between the northwest edge of the Chilhowee group rocks and the South Fork of the Shenandoah River is mostly covered but the few scattered outcrops that are present indicate the younger Cambrian rocks to be there in normal succession. These rocks are commonly steeply dipping to the northwest, vertical, or overturned and dip steeply to the southeast.

BLUE RIDGE OVERTHRUST

In Rockingham County the Geologic Map of the Appalachian Valley in Virginia (1933) shows the Blue Ridge overthrust present only in the northeastern part of the county for a distance of about 6 or 7 miles. The

Valley Map does not show the fault in the southeastern part of the county and the writer saw no evidence for the fault in that area. The northeastern part of Rockingham County lies in the Elkton area mapped by P. B. King and John Rodgers, and the problem of the Blue Ridge overthrust is discussed in some detail by King (1950, pp. 47-50).

King found a number of faults in the rocks on the northwest side of the Blue Ridge but none of them is suggested as being part of a Blue Ridge overthrust. Some of the faults are shown as thrust faults with a northeast trend, and some are mapped as northwest trending faults with a dominant strike-slip movement. Others are shown as high angle faults with dominantly vertical movements. As best as can be determined from recent work, there is no good evidence for a Blue Ridge overthrust in Rockingham County.

CENTRAL PART OF COUNTY

East of Massanutten Mountain and Its Trend

Structurally the area east of the topographic prominence of Massanutten and its southwestward trend differs from the area to the west of Massanutten Mountain and its trend. The southern part of this belt east of Massanutten Mountain consists principally of Cambrian and Ordovician limestones and dolomites which dip steeply to the northwest. At some places, particularly in the Conococheague limestone, considerable intraformational folding is present. The details of the minor structures generally cannot be determined because of the extensive alluvial cover. Northeast of the old Harrisonburg power plant, about 2.5 miles southwest of Island Ford, the rocks dip steeply to the northwest but some dips are vertical and some beds are overturned and dip to the southeast. The axes of many small folds strike north-northeast, but some fold axes strike northwest and thereby cut across the northeasterly trend of the formations.

A thrust fault, of relatively small stratigraphic displacement extends northeast from near Piney Mountain to near Shenandoah, Page County, a distance of about 8 miles. In this area the Edinburg formation cannot be distinguished readily from the Martinsburg shale and structural details are difficult to decipher in places. The Edinburg formation seems to be missing from near Piney Mountain to the vicinity of Humes School. The New Market and Lincolnshire are absent from the latitude of East Point to near the latitude of the town of Shenandoah, Page County. West of East Point the outcrop width of the New Market and Lincolnshire is greater than normal, probably as a result of faulting and of folding. About 0.8 mile west of East Point is a small klippe of upper Beekmantown (possibly some New Market) surrounded by Martinsburg shale. The klippe is well exposed on all sides except the southwest end that appears to be completely enveloped by the Martinsburg shale. About 1 mile southwest of East Point is an irregular-shaped eastward protruding outcrop of Martinsburg shale nearly surrounded by Beekmantown dolomite. The feature appears to be fenster-like and seems to have resulted from erosion of a complexly and tightly folded area in which cross-folding was prominent. Several northwest trending folds are well exposed near a stream bank 0.25 mile southeast of the easternmost extent of the Martinsburg. The fault is nowhere exposed in cross-section so the dip cannot be stated accurately. In places there is small scale folding of the Beekmantown just east of the fault, suggesting that the fault plane may be folded. A short distance north of Humes School the trace of the fault forms a notch pointing to the east which indicates the fault has a gentle eastward dip in that area. Low dip and warping of the fault surface are further indicated by the presence of the klippe and semi-fenster west of East Point.

About 0.9 mile south of East Point and 1.5 miles west of Millbank is a small area of considerable folding and probably some small scale faulting. Many changes of strike and dip occur in a short distance and there is no discernable pattern to the structures. To the east, and on the east side of State Road 639, there is a syncline in which some of the New Market and Lincolnshire rocks are preserved. There is small scale folding within the syncline and the syncline seems to be faulted along the southern margin. A small southeast dipping thrust fault along the southeastern bank of Quail Run is postulated to account for the abrupt ending of the synclinal structure and for the extreme confusion in strikes and dips in the general area.

Piney Mountain, about a mile northeast of McGaheysville, is conspicuously higher than any of the hills in its immediate vicinity and is mapped as an outlier of Massanutten sandstone preserved in a downfold. Dips in the Martinsburg shale at the base of Piney Mountain are commonly steep, some are vertical and overturned and suggest that Piney Mountain may be interpreted as a syncline. In spite of a thorough search, no definite outcrop of Massanutten sandstone could be found on Piney Mountain, the top of which is relatively flat and covered with blocks of sandstone. The blocks strongly resemble Massanutten sandstone, are mostly angular and little weathered, and apparently have not been moved very far from their place of origin.

In the bed of Bonnie Brook on the southwest side of Piney Mountain is about 100 feet of fine-grained greenish-gray sandstone that strongly resembles the rock just below the Massanutten sandstone in the area of Massanutten Mountain. The lack of a definite white sandstone outcrop at the top of Piney Mountain makes it impossible to prove conclusively that the Mountain is an outlier of Massanutten sandstone, but the available evidence seems to favor this interpretation.

The Martinsburg shale southeast of Massanutten Mountain probably is considerably folded and dips are commonly steep. Lack of readily identifiable horizons in the Martinsburg makes it impossible to determine the structure accurately or to determine the exact amount of folding that has taken place. It is likely that intraformational faulting occurs in this area but no mappable faults were observed.

MASSANUTTEN MOUNTAIN

The Massanutten synclinal complex reaches across the county in a northeast and southwest direction and extends far beyond the county boundaries in both directions. The topographic prominence of Massanutten Mountain extends from near Strasburg, Shenandoah County to just northeast of U. S. Highway 33 between Penn Laird and Montevideo in Rockingham County, a distance of approximately 50 miles. From the Page County line the main part of the mountain extends to the southwest for a distance of about 10 miles into Rockingham County. The greatest width in the county is about 2.5 miles and the least width is about 1 mile. Near the Page County line the mountain has four ridges of Massanutten sandstone but the northwestern two ridges join at Lairds Knob. The southeastern two ridges extend about 4.5 miles farther southwest where they join at "The Peak" which marks the southwestern terminus of Massanutten Mountain (Pl. 17B). A belt of Martinsburg shale, less than 0.5 mile wide and about 5 miles long, separates the northwestern ridges from the southeastern ridges. Almost all the younger rock has been eroded from the areas between the two northwestern ridges which join to form a single ridge in the vicinity of Lairds Knob. At Fridley Gap the syncline formed by the two northwestern ridges is approximately symmetrical; the limbs dip about 60°.

The Martinsburg shale is exposed in what appears to be an anticline between the northwestern and southeastern synclines. Dips on the northwest flank range from about 45° to 65° to the northwest and dips on the southeast flank average about 60° to the northwest. These dips suggest an anticline overturned to the southeast and with an axial plane dipping northwest. This is contrary to the usual southeast direction of dip of the axial planes of most Appalachian folds.

In the vicinity of Runkles (Ruckles) Gap the southeastern syncline has anticlinal dips on its flanks; the northwestern limb dips 60° to 80° northwest and the southeastern limb dips about 80° to the southeast. The syncline maintains the shape of a fan fold for several miles northeast and southwest of Runkles Gap. Apparently the southeastern trough is deeper than the northwestern trough locally, and pressure from the east pushed the southeastern trough westward under the northwestern trough. Northeast of the latitute of Lairds Knob the southeastern syncline is closely squeezed but toward the southwest the limbs become progressively farther apart until the area of plunge is reached. Near the southwestern limit of outcrop of the Massanutten sandstone, vertical to steep southeast dips on the southeast flank and dips of about 30 degrees to the southeast on the northwest flank indicate overturning of the syncline to the northwest in this area. At "The Peak" at the southwestern end of the fold in sandstone, there is a plunge of 20 degrees in a N. 50° E. direction.

Southwest of Massanutten Mountain the much crumpled Martinsburg shale occupies the center of the synclinal structure. A variety of dip directions is found in this incompetent formation and the axis of the main structure cannot be located accurately because of small folds and probable small faults. At its narrowest point, in the vicinity of Cross Keys Battle Monument and Mill Creek Church, the width of outcrop of the Martinsburg is about 2.25 miles. The squeezing in some places and expansion of the synclinal structure in other places corresponds to changes in trend of the Cambrian and Ordovician formations to the southeast.

AREA BETWEEN MASSANUTTEN MOUNTAIN AND PULASKI-STAUNTON FAULT

Northwest of Massanutten Mountain and its trend and southeast of the Pulaski-Staunton fault, Cambrian and Ordovician formations crop out in long narrow bands. Dips in the formations are commonly steep and inclined toward the southeast. The rocks in this area form the northwest flank of the Massanutten synclinal complex.

PULASKI-STAUNTON FAULT ZONE AND ASSOCIATED STRUCTURES

The northeast-southwest trace of the Staunton fault extends from the junction with the Pulaski fault in Rockbridge County to near Endless Caverns, Rockingham County, Virginia, a distance of about 65 miles. The fault dies out to the northeast near the axis of a plunging anticline, one or two miles southwest of the entrance to Endless Caverns (Butts, 1933, Thornton, 1953). With respect to the southwestern termination, Butts (1940, p. 452) wrote: "At its southwest end . . . , the Staunton fault merges with the Little North Mountain fault in a complex tangle that has not been satisfactorily explained, . . . " Recently (Edmundson, 1958; Bick, 1960) the Staunton fault has been shown to be the northeastern extension of the Pulaski fault and the fault is designated as Pulaski-Staunton fault. The Elbrook dolomite borders the fault on the southeast (upthrown) side throughout the length of the break, except near the northeast end where successively younger formations, Conococheague, Chepultepec and Beekmantown, occur on the upthrown side until the fault dies out in the Beekmantown. The northwest (downthrown) side is occupied mainly by the Beekmantown dolomite. The klippe near Burketown, Virginia, is genetically related to the Staunton fault (Butts, 1940, pp. 451-452; 1933).

The trace of the Pulaski-Staunton fault across Rockingham County is a generally straight line but just south of the county line it makes an "S" curve. The Elbrook dolomite borders the fault on the upthrown side for about 14 miles in the southern part of the county. In the northern part of the county, where the stratigraphic throw begins to decrease, the Conococheague limestone occupies this position for about 8 miles, the Chepultepec limestone for less than 0.25 mile, and the fault ends in the Beekmantown dolomite. Where the Elbrook dolomite is adjacent to the fault only about the upper half of this formation is present. In general, the upper part of the Beekmantown forms the northwest (downthrown) side of the fault. The stratigraphic displacement varies considerably but is generally about 4,000 feet or more where the Elbrook and Beekmantown are contiguous. To the northeast the displacement is about 2,000 feet where the fault is bordered by the Conococheague and the Beekmantown, and the displacement progressively decreases toward the northeast.

The dip of the fault is difficult to determine accurately because the fault is a zone and exposures show only a very small part of the entire zone. Possible clues to the dip of the fault are: (1) associated fracture cleavage, (2) dip of beds adjacent to the fault, (3) migration of fault outcrop because of topography, and (4) associated drag-folds. The above criteria indicate a general dip for the fault of between 30 and 55 degrees. Many of the characteristics of the Pulaski-Staunton fault are more nearly like those of high angle reverse faults to the northeast than those of the low angle thrusts in the southern Appalachians. Folding of the fault is indicated just south of the Rockingham-Augusta County line where the fault trace makes an "S" curve. Also, in this same area formations in the allochthon are considerably folded locally, and folding of the autochthon is shown by the preservation of a klippe in a synclinal structure immediately north of the "S" curve. No individual fold, however, is traceable from the autochthon, across the fault, and into the klippe.

In a roadcut in the northwest environs of the city of Staunton, Augusta County, are exposed at least 1,000 feet of breccia, rubble, and rotated blocks of various sizes in the Staunton fault zone. Discontinuous exposures across the fault zone at a number of places in Rockingham County indicate a comparable width for the zone. Movement was probably concentrated along weak zones, within the fault; the intervening areas being distorted and broken, but undergoing relatively small displacement.

In places the dolomite and limestone in the fault zone has been considerably silicified; some of this cherty material is porous and some is dense and jaspery. Near Massanetta Springs there are silicified beds that have retained all outward appearances of bedded dolomite. The fault zone has topographic prominence throughout much of its extent and forms isolated hills in some areas; at many places the height clearly results from silicification along the fault.

KLIPPEN

During erosion of an overthrust sheet, if an isolated remnant is left, this remnant of the overthrust sheet is called a klippe. Four klippen associated with the Pulaski-Staunton fault are mapped in Rockingham County, only one of which was described previously. The largest, that near Burketown, Augusta County, is partly in Rockingham County and partly in Augusta County. This klippe was mapped by Butts (1933) and described in connection with the Staunton fault (Butts, 1940, pp. 451-452). Butts (1940, p. 468) recorded that in the Appalachian Valley, klippen are not common and mentioned the occurrence of only two. Recently, the presence of several klippen in southwestern Virginia has been noted (Miller and Brosgé, 1954, pp. 168-205). Klippen are of interest particularly because they indicate something of the former extent of a thrust sheet and suggest warping of a fault surface if their presence cannot be explained by topographic irregularities. To facilitate discussion, the four klippen recorded in Rockingham County are called: the Burketown klippe, the Dayton klippe, the Harrisonburg klippe, and the Madison klippe.

Burketown klippe—The Burketown klippe, partly in Rockingham County and partly in Augusta County, is the largest klippe in the Appalachian Valley in Virginia. It has a maximum north-south length of about 5 miles (about 2 miles in Rockingham County,) a maximum width of about 2 miles, and an area of approximately 8 square miles (about 2.6 square miles in Rockingham County). The formations represented are: Conococheague limestone, Chepultepec limestone, Beekmantown dolomite, New Market limestone, and Lincolnshire limestone. Where the Conococheague is adjacent to the Martinsburg the stratigraphic displacement is about 5000 feet. The general strike of the rocks in the klippe is north-south, showing a horizontal rotation of about 30 degrees from the usual structural trends of the area. Some of the dips within the klippe are overturned, indicating that forces rotational in a vertical plane were present during deformation. On the east side of the klippe exposures at and near the fault are usually bordered by the Conococheague limestone and the Edinburg formation or the Martinsburg shale. Where the fault occurs between the Conococheague and the shaly base of the Edinburg or the Martinsburg, the limestone shows much fracturing, some veining and recrystallization, and the shale is considerably veined with white calcite. If limestones occur on both sides of the fault there is a zone of complete recrystallization and identification of a formation is difficult. Along the west side of the klippe sections of the New Market and Lincolnshire limestones are faulted off at both ends, and where these formations are not present the Beekmantown is on the northwestern edge of the klippe. The New Market and Lincolnshire are commonly vertical or overturned and dip toward the Beekmantown. On a hillside along the western boundary of the klippe erosion has exposed the fault and the fault appears to dip about 10 degrees to the east. The northern end of the klippe forms an impressive cliff (Pl. 13B) and the inclination of the trace of the fault along the face of the cliff is about 10 or 15 degrees to the east. The Martinsburg shale of the autochthon is considerably veined with white calcite adjacent to the fault but otherwise shows little effects from the faulting. There is a thick zone of dolomite in the Conococheague within the klippe which in places is broken, recrystallized, and brecciated.

Dayton klippe—This klippe, just east of Dayton, has a northeast-southwest length of about 3 miles, a maximum width of 0.7 mile, and an area of approximately 1.5 square miles. The southern end of the Dayton klippe is 3 miles north-northeast of the Burketown klippe and about 4.5 miles northwest of the present major trace of the Pulaski-Staunton fault. The Dayton klippe is entirely surrounded by the Martinsburg shale. Most of the klippe consists of Beekmantown dolomite, but along the convex northwest edge are incomplete sections of the New Market, Lincolnshire, and Edinburg limestones. The effects of faulting on the bordering rocks are essentially the same as those described for the Burketown klippe. The general trend of the klippe is northeast-southwest and the dips are steep and commonly overturned. A series of hills gives good topographic expression to the klippe, and the line of the encircling fault can be traced on aerial photographs.

Other klippen—The Burketown klippe was mapped by Butts (1933) and the Dayton klippe was mapped by the present writer in 1953 (Brent, 1955). Two small klippen, near Harrisonburg, were mapped by the writer in 1953 (Brent, 1955) and later were described by Brent and Young (1955, pp. 1685-1686). These two structures near Harrisonburg are considered to be klippen by the writer, although the identification of the rock above the fault is uncertain. No megascopic fossils have been found and the rock is thought by the writer and others to be Edinburg and by others to be Beekmantown.

Harrisonburg klippe—The northeast-southwest length of the Harrisonburg klippe is about 1 mile, the maximum width is 500 feet, and the distance from the major trace of the Staunton fault is about 1.8 miles. The klippe is composed of Edinburg limestone and is surrounded by the upper Beekmantown dolomite. On the east face of the Betts quarry the structural details can be observed down to a depth of about 50 feet where quarrying operations have exposed the fault between the Beekmantown and Edinburg (Pl. 15A). About 15 to 18 inches of "gouge-like" material marks the fault zone wherever the fault can be seen. This "gouge" consists of small angular pegs which are so completely fractured that they readily break down into numerous smaller particles with the application of very slight pressure (Pl. 16A). On the west-facing quarry wall the fault extends vertically downward as a bedding fault and is intricately folded in places. This same fault is exposed as a gently folded, nearly horizontal zone on a north-facing wall (Pl. 15B). Several warped, gently dipping reverse faults occur within the klippe itself, and at least one of these faults has a number of associated gash fractures filled with white calcite. Some of the rock in and adjacent to the klippe shows the effects of considerable squeezing, plastic deformation, and recrystallization.

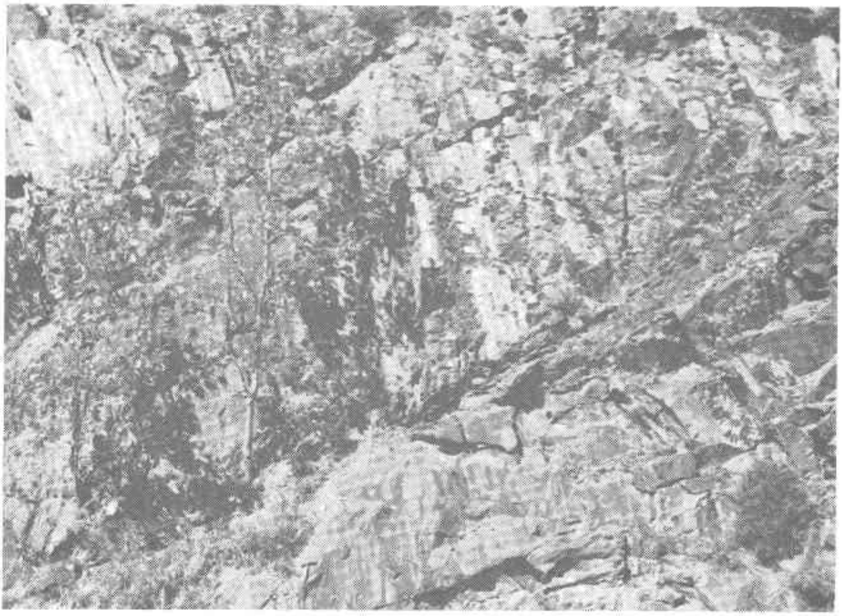
Madison Klippe—This klippe lies about 1200 feet to the southwest of the Harrisonburg klippe and both have similar stratigraphic relations. The Madison klippe strikes a little west of north, and is about 1500 feet long and 500 feet wide. Since it is known only from surface outcrop, nothing is known of the structural details. The Harrisonburg and Madi-

Plate 14

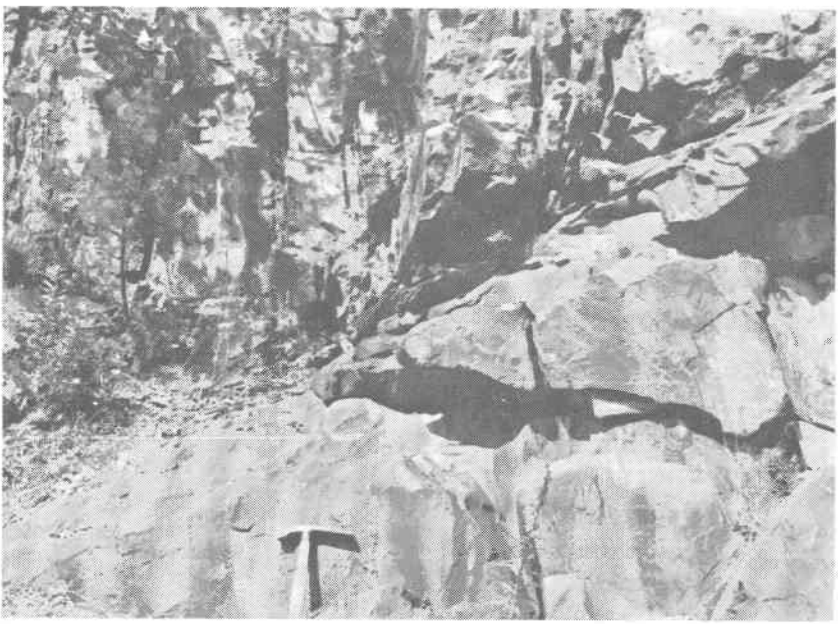
A. Northwest dipping reverse faults on north wall and near east end of Brocks Gap in Little North Mountain.

B. Drag associated with northwest dipping reverse fault at Brocks Gap in Little North Mountain.

Plate 14

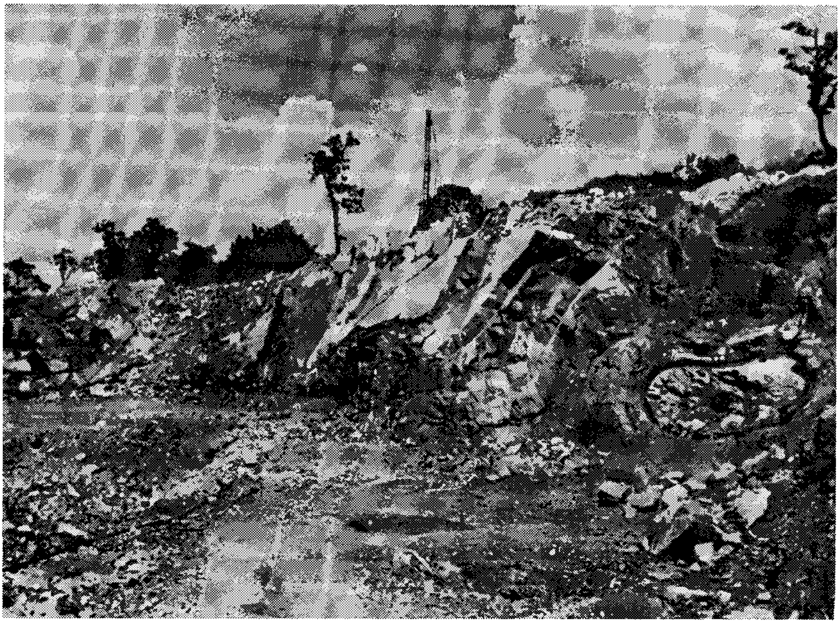


A. Northwest dipping reverse faults on north wall and near east end of Brocks Gap in Little North Mountain.



B. Drag associated with northwest dipping reverse fault at Brocks Gap in Little North Mountain.

Plate 15

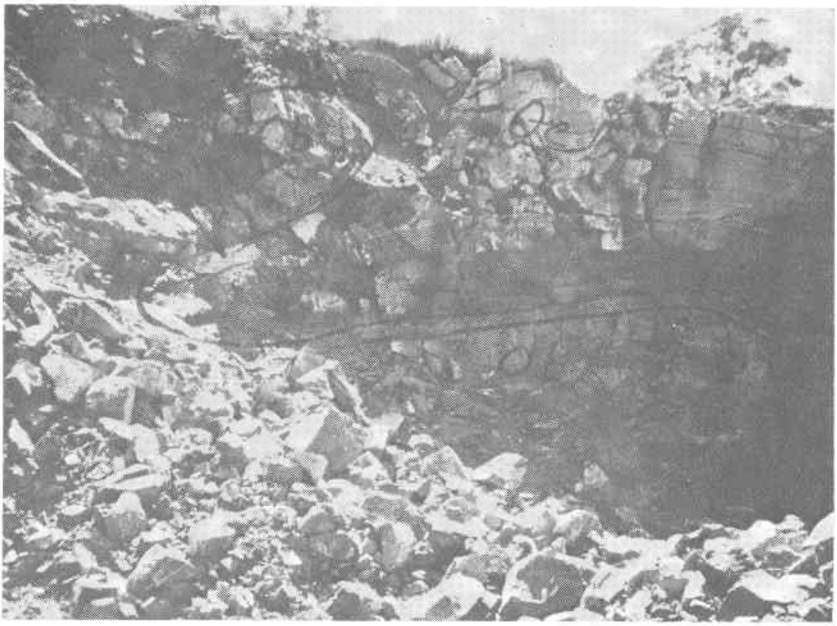


A. View toward north in the Betts quarry east of Harrisonburg. Closed line shows trace of fault on east wall; Beekmantown dolomite enclosed by line, most of the other rock shown is Edinburg (?) limestone within a klippe.

B. View toward south in the Betts quarry east of Harrisonburg. Curved line shows trace of folded fault. Ob, Beekmantown formation; Oe, Edinburg limestone.

Plate 15

A. View toward north in the Betts quarry east of Harrisonburg. Closed line shows trace of fault on east wall; Beekmantown dolomite enclosed by line, most of the other rock shown is Edinburg (?) limestone within a klippe.



B. View toward south in the Betts quarry east of Harrisonburg. Curved line shows trace of folded fault. Ob, Beekmantown formation; Oe, Edinburg limestone.

son klippen do not stand out topographically and are fairly small features, and other similar structures may exist in the Rockingham County area.

A small chert hill 3.2 miles N. 58° E. of the town square in Harrisonburg is an anomolous feature in an area of Edinburg limestone and may be a klippe, but the evidence is insufficient to warrant a definite statement. The Edinburg normally contains no chert, although some chert particles were seen in the formation about 1/2 mile south of Bridgewater. The chert on top of the hill northeast of Harrisonburg is similar to the heavy porous chert of the Beekmantown or to the "reefy" chert that occurs locally in the Lincolnshire. The limestone at the base of the hill shows many irregular changes in strike and dip in short distances and suggests tight complex folding and faulting.

AREA BETWEEN PULASKI-STAUNTON FAULT AND LITTLE NORTH MOUNTAIN FAULT

One large fold west of the Pulaski-Staunton fault is the Harrisonburg syncline which extends southwest from the city of Harrisonburg to the vicinity of Spring Hill (Long Glade), Augusta County. The Martinsburg shale occupies the center of this fold which contains the entire Dayton klippe and most of the Burketown klippe. The axial plane of this syncline appears to be vertical but incompetent folding of the associated formations makes this difficult to determine accurately.

The Park View anticline, just west of the town of Park View, is a doubly plunging fold about 2.5 miles long and 0.4 mile wide. This fold strikes northeast-southwest, is convex toward the northwest, and the axial plane dips steeply to the southeast. Both flanks of the anticline form hills, underlain by cherty Lincolnshire limestone, and the Beekmantown dolomite crops out along the low axial region.

About 0.5 mile northeast of the Park View anticline is a smaller anticline with the same formations involved in the folding but of somewhat different structural characteristics. This fold, about 1 mile long and 0.5 mile wide, has convex sides and strikes almost due north. Dips on the east flank are about 60 degrees east and those on the west flank about 35 degrees to the west, indicating that the axial plane dips toward the west. The reasons for the inclination of the axial plane in this direction are not entirely clear but may be controlled by a faulted larger anticline to the east. The intervening sharply folded syncline is only about 1000 feet wide.

Northeast of Dale Enterprise and just north of U. S. Highway 33, the New Market and some of the Lincolnshire limestone are preserved in a small syncline. The cherty Lincolnshire gives topographic expression to this small fold which is about 1/4 mile wide, about 3/4 mile long, and trends a little east of north.

A finger-like projection of the Martinsburg shale, which is part of the main body of Martinsburg in the Massanutten synclinal complex, extends into Rockingham County for about 8 miles southwest of the Shenandoah County line. This shale occupies the center of a narrow syncline northwest of the northeast plunging anticline in which the Pulaski-Staunton fault terminates. The syncline stops by plunging slightly less than 0.5 mile southeast of Lacey Spring.

The major structure immediately west of this syncline is an anticline in which Conococheague limestone is the oldest rock exposed and is here designated the Mayland anticline from the community of Mayland, about 2 miles southeast of Broadway. The Mayland anticline is outlined by a belt of New Market-Lincolnshire which terminates to the southwest by plunging about 1 mile northeast of the city limits of Harrisonburg. Along the southeastern side of the area of plunge of New Market-Lincolnshire are several small dominantly strike-slip faults that trend in a northerly direction. Although these faults have relatively minor displacement they have produced isolated blocks of New Market and Lincolnshire limestones.

One northeast trending fault, probably dominantly strike-slip, is about 2 miles long and cuts out the New Market and Lincolnshire limestones for about 1.5 miles on the east flank of the Mayland anticline. This fault dies out to the northeast in the vicinity of the Melrose Caverns. The fault seems to be intersected near its northeast end by an east-northeast trending strike-slip fault that offsets the New Market and Lincolnshire limestones to the west, south of Melrose Caverns.

South of the southwest plunge of the Mayland anticline and just east of the Harrisonburg city limits is a strike-slip fault that was previously mapped by Butts (1933). This fault has an apparent length of about 2 miles and has produced an offset of 1.25 miles in a belt of the New Market and Lincolnshire limestones. Several small folds involving principally the Lincolnshire limestone, just east of the fault, may have been produced by the same forces that caused the shear.

The Linville Creek syncline is on the Rockingham County-Shenandoah County line about 3 miles northeast of Timberville and extends southwest to approximately 38° 30′ north latitude, a mile or two north of Park View. The syncline is named for Linville Creek that flows through the central part of the fold from the southwest end of the syncline to Broadway, a distance of about 8 or 9 miles. Southwest of Timberville the Martinsburg shale occurs in the central part of the fold. The Martinsburg terminates to the southwest in three prominent digitations that are separated by Edinburg limestone. To the northeast the Martinsburg becomes very narrow and ends in a sharp projection about one-half mile west of Timberville. Just north of Timberville, within the Linville Creek syncline, is a small doubly plunging anticline of New Market-Lincolnshire surrounded by Edinburg limestone. This anticline is about 1.5 miles long in a northeast-southwest direction and about one-quarter of a mile wide. The axial plane of the fold is inclined steeply to the southeast; dips on the southeast flank are about 45° S. E. and dips on the northwest flank about 65° N. W. The anticline is reflected well in the topography as an anomolous ridge within an expanse of topographically lower Edinburg limestone.

LITTLE NORTH MOUNTAIN FAULT ZONE AND LITTLE NORTH MOUNTAIN

Little North Mountain fault zone and Little North Mountain are so closely related that for purposes of discussion they are considered to be a single structural segment. However, the two units are sufficiently distinct so that each can be described more or less independently.

LITTLE NORTH MOUNTAIN FAULT ZONE

The Little North Mountain fault extends completely across the county in a northeast and southwest direction for a distance of about 27 miles. The fault occurs on the Rockingham County-Augusta County line about 2 miles south-southwest of Briery Branch, on U. S. Highway 33 about 2.5 miles northwest of Hinton, on State Highway 259 about 0.3 mile northwest of Cootes Store, and on the Rockingham County-Shenandoah County line about 0.2 mile northwest of St. Lukes Church.

From the Augusta County line the fault trends to the northeast for about 3 miles with the Elbrook dolomite on the east side and the Brallier shale on the west side of the fault. Most of the thickness of the Elbrook probably is present here but an undetermined amount of the bottom of the formation has been removed by faulting. Some distance from the fault the Elbrook dips gently to the southeast but close to the fault many beds are steeply inclined to the southeast. The Brallier crops out for about 0.2 to 0.3 mile west of the fault and the beds are overturned and mainly dip steeply southeast.

About 3 miles northeast of the Augusta County line the strike of the fault changes and turns due east for about 1 mile then turns to resume its northeast trend. This bend may be attributed, at least partly, to folding of the fault. About 0.5 mile east of the fault, folding which corresponds to the bend in the fault, is indicated by three offset sandstone hills in the lower Conococheague. North of the main trace of the fault, where it trends east-west, are several areas of sandstone within the Brallier shale. These sandstone areas are mapped as Clinch (Tuscarora), but they could be Oswego or possibly Ridgeley. The two largest sandstone areas are surrounded by Brallier except for a short distance of contact with the fault. The larger of these extends about 0.4 mile in a north-south direction and about 0.3 mile in an east-west direction. One area of sandstone entirely surrounded by Brallier forms a small but conspicuous knob about 0.1 mile due west of an abandoned quarry in the Elbrook dolomite on the southeast side of the fault. Another apparently isolated sandstone area occurs about 0.3 mile north of the aforementioned quarry. The attitude of bedding in these sandstone blocks could not be determined. All these sandstone blocks are thought to have been broken from the Clinch (Tuscarora), carried up along the fault, and enclosed in the shale on the northwest side of the fault.

From the east-west trending part of Little North Mountain fault to the vicinity of U. S. Highway 33 is an area that is incompletely understood, about 4 miles long and about 0.5 mile to 1 mile wide, bounded on the east by the main trace of the fault. In this area, here called the Cooper Mountain area, the structure is complex and there is considerable cover by surface gravel. Formations represented in the Cooper Mountain area are: New Market and Lincolnshire, Edinburg, Martinsburg, Oswego, possibly Clinch (Tuscarora), and Millboro.

The New Market and Lincolnshire clearly have been much disturbed and have fault relations with rocks to the north and to the east. Fairly wide exposures of Edinburg occur in the northern part of the area and good outcrops of *Nidulites* bearing Edinburg limestone are in the southern part of the area. Between these two occurrences of Edinburg the bedrock is buried by gravel deposits but the formation is assumed be continuous beneath the cover. The Edinburg is faulted at its northern and southern ends and along much of its eastern side appears to be immediately northwest of the Little North Mountain fault. Outcrop width of the Martinsburg in the northern part of the area is about 1500 feet, but largely because of cover it is impossible to tell if the upper and lower contacts are normal or faulted. Just north of Dry River is an apparently normal contact between Oswego and vertical greenish sandstone beds, which are probably the uppermost Martinsburg. The greenish sandstone beds resemble the *Orthorhynchula* beds, but no fossils were found at this locality so identification is uncertain. To the southwest the outcrop width of the Martinsburg becomes progressively more narrow and the contacts commonly are covered. South of Dry River the Martinsburg probably is faulted on one or both sides but the nature of faulting is unknown. The Martinsburg is terminated to the south by a fault.

Just south of U. S. Highway 33 is Cooper Mountain, a prominent, mile long, north-south trending hill of Oswego sandstone which is faulted on its north end. To the south Cooper Mountain ends in a steep cliff of vertical to overturned and steeply eastward dipping sandstone beds. The western part of this exposure has at least one steep westerly dipping shear but the amount of displacement is unknown. The Oswego appears to be stratigraphically overlain to the west by Clinch (Tuscarora), but since no fossils are present and the Juniata seems to be absent, it would be virtually impossible to separate accurately the Oswego and Clinch (Tuscarora) formations if both were present. At Dry River the Oswego bends toward the southwest and continues as a low ridge for almost 2 miles and ends rather abruptly, apparently by faulting. The Clinch (Tuscarora), if present, occurs on the west side of Cooper Mountain and is cut out about 0.5 mile south of Dry River. Only the upper part of the Millboro shale appears to be present and is in normal contact with the Brallier shale to the west, although both formations are overturned and dip steeply to the southeast. The Millboro stops by faulting to the north and south. The beds in Cooper Mountain apparently once were connected to the beds in Little North Mountain but because of faulting the two areas now are separated by about 1.5 miles of Brallier shale.

The movement along the east-west trending fault at the north end of Cooper Mountain appears to be dominantly strike-slip; the south side moved relatively to the west. This movement could have produced the bend in the Oswego sandstone at Dry River and could account for the almost due north strike of Cooper Mountain. The strike-slip fault is not exposed but stratigraphic relations extend it to the east to the Little North Mountain fault. Since the Elbrook dolomite on the east side of Little North Mountain fault shows no perceptible off-set, it appears that movement along the strike-slip fault may have preceded some major northwest thrusting movements in the area.

As an alternative interpretation the east-west fault that truncates Cooper Mountain might be considered to be the same fault that cuts out the bottom part of the Millboro along the west side of the Cooper Mountain area. The east-west fault would be an exposure of the thrust fault that underlies the Cooper Mountain area where this fault turns and joins the Little North Mountain fault. In either interpretation the sense of movement of the east-west fault is the same; the south side has moved to the west relative to the north side.

The area west of Little North Mountain fault and between the fault at the north end of Cooper Mountain and the fault at the south end of Little North Mountain contains some confusing structural and stratigraphic relationships. Just west of Little North Mountain fault is a belt of shale that appears to be Martinsburg but the identification is uncertain. West of the Martinsburg (?) is a belt of Ridgeley sandstone that contains large spirifer-type brachiopods in an outcrop behind a small church. West of this belt of Ridgeley sandstone is the Millboro shale. The Ridgeley pinches and swells and in places is absent for short distances. The thickness variations are difficult to account for on either a sedimentational or a structural basis, but structural control seems more probable. Apparently there is a southeast dipping reverse fault between the Martinsburg (?) and the Ridgeley which cuts out the Ridgeley in places and the shale moved in to occupy the space between the disconnected segments of Ridgeley. During deformation this belt of Ridgeley was bent and deformed and evidence of bedding in the sandstone was largely destroyed.

Between U. S. Highway 33 and State Highway 259 the Little North Mountain fault zone involves a number of different formations, including the Elbrook, Conococheague, Beekmantown, New Market, Lincolnshire, and Edinburg formations. Where the Elbrook, Conococheague, and Beekmantown formations are next to each other because of faulting, there is considerable difficulty in separating them. Commonly the formations can be identified on the basis of the sandstone in the Conococheague and heavy porous chert in the Beekmantown. Where the Edinburg is in proper stratigraphic sequence, no fault is shown on the geologic map on either side of the formation. However, the belt of Edinburg limestone along the east side of Little North Mountain is much thinner than the Edinburg farther east and lacks much of the typical lithology. Further, the Edinburg limestone along the strike in the Cooper Mountain area is typical of the Edinburg lithology farther east. The differences in lithology and thickness of the Edinburg in the belt along the southeast side of Little North Mountain may be related to conditions of original sedimentation, but to the writer it seems possible that faulting may have caused omission of some of the Edinburg northwest of the Little North Mountain fault.

Northeast of State Highway 259 the Little North Mountain fault and Little North Mountain approach each other and near the Shenandoah County line the fault is a short distance up on the slope of the mountain. For a distance of about 3.5 miles northeast of State Highway 259 the Little North Mountain fault is between the Conococheague limestone and the New Market-Lincolnshire. Northeast of this point the New Market-Lincolnshire and Edinburg are cut out and the fault is between the Conococheague and Martinsburg. Zones of fault breccia and faulting exposed on the walls of the old Mundy quarry, northeast of Cootes Store, indicate intraformational faulting in the Conococheague as much as 0.75 mile or so east of the present trace of the main fault.

The dip of the Little North Mountain fault seems to vary along the strike; it is steep in its northeastern exposures in the county and more gentle to the southwest. A west facing quarry wall in the Elbrook dolomite about 1.5 miles west of Clover Hill exposes the southeast side of the fault. The rock is well exposed but the fault itself is covered and little information is available here on the dip of the fault. Three miles south-southwest of Cootes Store, in a quarry operated by C. S. Mundy, is an exposure of what appears to be the main trace of the Little North Mountain fault. In this quarry the stratigraphic relations show the Elbrook dolomite to the east faulted against the Beekmantown dolomite on the west. The fault is not a clean break; instead it is a zone of movement showing squeezed, broken, and dislocated beds, and the only information that can be obtained here regarding the dip of the fault merely suggests that it is neither vertical nor horizontal. On the north side of State Highway 259 about 1,700 feet west of Cootes Store, where the fault is crossed by the Highway, is an exposure of dolomite breccia, but this offers no real clue to the actual attitude of the fault surface. About 0.75 mile southwest of Cootes Store the fault is exposed in the valley of a small unnamed stream. The Conococheague limestone forms a scarp, about 6 or 8 feet high, on the east side of the stream and the dip of the fault surface is 70° to the southeast (Pl. 13A). South of U. S. Highway 33, folding of the fault and the present irregular trace of the fault indicate that the dip is less steep than it is to the northeast. An accurate determination of the dip cannot be made but the dip probably is no greater than 50°.

Stratigraphic displacement of the fault varies considerably along the strike but apparently is greatest in the southwestern exposures in the county. Here the Cambrian Elbrook dolomite is brought into contact with the upper part of the Devonian Brallier shale giving a maximum stratigraphic displacement of approximately 10,500 feet. Between U. S. Highway 33 and State Highway 259 there is considerable variation but where the main fault is between the Elbrook and Beekmantown there is a maximum stratigraphic displacement of approximately 4,000 feet. Near the Shenandoah County line where the fault is between the Conococheague and the Martinsburg the maximum stratigraphic displacement is about 3,000 feet.

LITTLE NORTH MOUNTAIN

Previous publications on the geology of Little North Mountain have dealt principally with localities north of Rockingham County. Giles (1927, p. 53) considered Little North Mountain to be ". . . a faulted monocline of overturned beds with steep southeastward dip . . ." Further, he said that the faults associated with the mountain are southeasterly inclined overthrusts and that the major overthrust has a continuous trace on the west side of the mountain. Other faults are distributive from the major overthrust, discontinuous, and merge with the major thrust. Butts and Edmundson (1939) and Edmundson (1940) differed with Giles in that they could not identify a continuous major overthrust on the west side of Little North Mountain. Also, Butts and Edmundson accounted for marked variations in thickness or absence of certain formations by assuming discontinuous sedimentation instead of faulting as postulated by Giles. The writer's studies of Little North Mountain all have been south of the areas previously described.

In Rockingham County Little North Mountain is the steep northwest flank of an overturned faulted anticline. The beds in the mountain vary in dip from vertical to overturned, dipping to the southeast. Most of the dips are steep but along the top of the mountain dips as low as 25° to the southeast occur. The best exposures in the mountain are on the north wall of Brocks Gap, a water-gap of the North Fork of the Shenandoah River. All the formations present at Brocks Gap continue, with variations in thickness, to the Shenandoah County line to the northeast. The Oswego-Juniata occurs at the crest of the mountain from Brocks Gap to about 3 miles to the northeast, and from there to the Shenandoah County line the Clinch (Tuscarora) is on the top of the mountain. The Cayuga group and the Helderberg group seem to be considerably thinner near the Shenandoah County line than at Brocks Gap but accurate observations of these formations are difficult because of cover. The most readily noticeable changes in thickness occur in the Oswego-Juniata that is about 650 feet thick at Brocks Gap and near the Shenandoah County line only about 200 feet thick. Between Brocks Gap and Hopkins Gap, about 10 miles to the southwest, most of the formations vary in thickness but the most striking changes occur in the Oswego-Juniata. Approximately 3 miles southwest of Brocks Gap the Oswego-Juniata is absent for about a thousand feet and is absent also at a locality about 6.5 miles southwest of Brocks Gap. Southwest of Hopkins Gap the only formations that can be well observed in exposure are the sandstones, the Oswego-Juniata, Clinch, and the Ridgeley. Little can be said about the other formations that normally occur in Little North Mountain, the Clinton, Cayuga, and Helderberg, except that they seem to be present. Near the southwestern end of the mountain the formations are curved in several places and minor offsets may occur. The mountain ends abruptly against what appears to be a northwest trending strike-slip fault, similar to the fault at the north end of the Cooper Mountain area. The formations at the southwest end of Little North Mountain terminate in a bend which may have resulted from drag along the truncating fault.

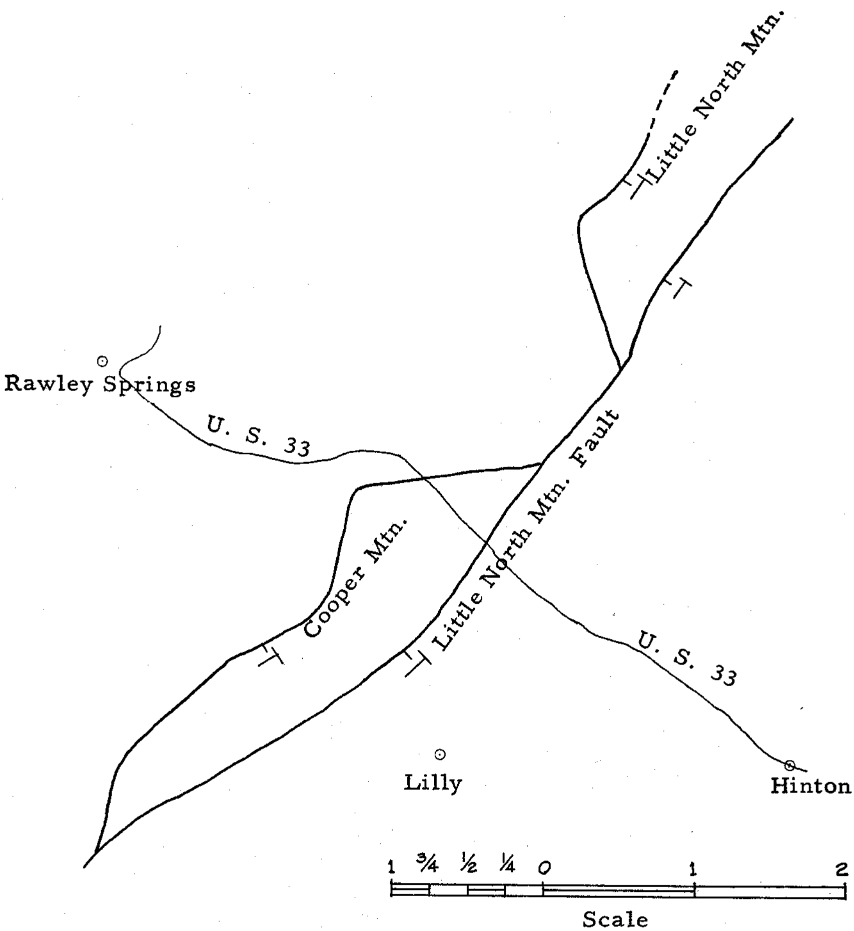


Figure 2.—Sketch of the area in the vicinity of the southwestern end of Little North Mountain showing different structural interpretation from that on the geologic map.

The fault that occurs at the southwestern end of Little North Mountain conceivably could be a thrust branching from the Little North Mountain fault. In this case the thrust would underlie the southwestern end of Little North Mountain and the trace of the fault would extend northwest from the main fault, go around the southwestern end of Little North Mountain and parallel the mountain for an unknown distance on the northwest side. There are indications of faulting on the northwest side of Little North Mountain toward its southwestern end but the formations in that area consist of shales which are poorly exposed and it is virtually impossible to detect a fault under such conditions. If Little North Mountain is truncated by a thrust fault the sense of movement at the southwestern end would be the same as if it were truncated by a strike-slip fault; the north side would have moved to the west relative to the south side. Figure 2 is a sketch showing a different interpretation than was used on the geologic map for the faulting at the southwestern end of Little North Mountain and at the northern end of Cooper Mountain.

Faulting at Brocks Gap —At the eastern end of Brocks Gap two northwest dipping faults are exposed on the north wall of the gap (Pl. 14A). These faults, both of which are reverse faults according to the drag (Pl. 14B), occur at or near the boundary between the *Orthorhynchula* zone of the Martinsburg shale and the Oswego sandstone. The upper fault dips approximately 40° and the lower fault about 25°, so the two faults converge toward the northwest and probably join underground, but they are 6 or 8 feet apart at the level of the highway. Between the faults is a wedge of fossiliferous sandstone belonging to the *Orthorhynchula* zone. Figure 3 shows the faulting at Brocks Gap as exposed on the north wall of the gap. The stratigraphic displacement of the northwest dipping reverse fault at Brocks Gap is unknown but may be less than 100 feet at the gap. The presence of this fault gives ample evidence of the tendency for such faulting to occur at this horizon, and it is possible that this fault extends along the east side of Little North Mountain for many miles, with varying stratigraphic displacement. On the other hand, there might be a series of discontinuous northwest dipping reverse faults in this stratigraphic position. Such faulting, either continuous or discontinuous, could easily explain the variations in thickness of the Oswego sandstone that occur in Little North Mountain. The changes in thickness of the Oswego might result from original sedimentation and conceivably could have been caused by erosion; however, where the Oswego is thin or absent the omission of section appears to begin at the bottom and proceed toward the top of the formation. Also, the changes in thickness are of considerable magnitude, occur in several places, and take place in a fairly short distance. The evidence, although by no means conclusive, suggests that faulting is a probable cause for the large variations in thickness of the Oswego along the east side of Little North Mountain.

Northwest dipping reverse faults, similar to the faulting at Brocks Gap, have been described by Miller and Fuller (1954, pp. 222-224) in connection with the Cumberland Mountain monocline in southwestern Virginia. In their description of this faulting they stated: "The Cumberland Mountain monocline is distinguished by a series of small parallel reverse faults, which have no counterparts elsewhere in the district. All the faults of this type that have been seen have steep northwesterly-dipping planes along which the upthrown beds are on the northwest side. Most of the faults have a displacement of about 20 to 50 feet, which normally results in the duplication of from 5 to 15 feet of beds." . . "Slickensides on the face of the fault . . . indicate that the beds north of the fault moved eastward as well as upward along the fault plane. There is little doubt but that many of these reverse faults exist along the Cumberland Mountain monocline though only a few have been seen. All those known in the district are of small displacement, but a reverse fault of the same type with a displacement of several hundred feet is responsible for the twin-crested ridge of Cumberland Mountain at Falling Water Gap, 1¼ miles north of Rose Hill and just outside the district. Though small, these reverse faults have a special significance, for they show that deformation stresses existed at some time that tended to push rocks on the northwest above those on the southeast, whereas all the major overthrust movements of the region were toward the northwest."

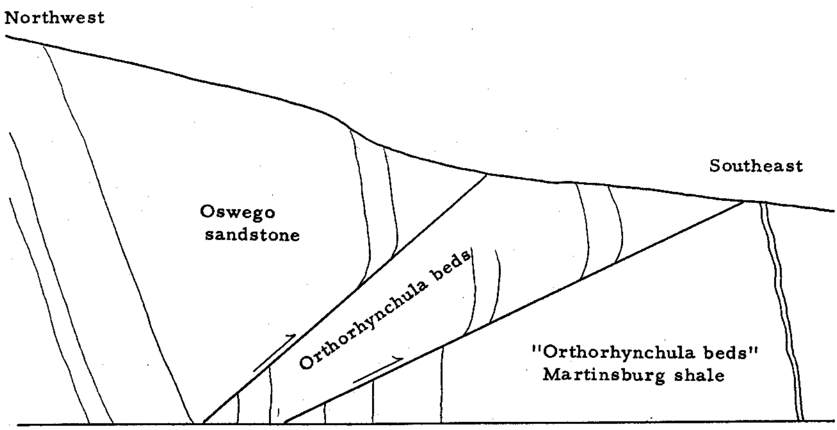


Figure 3.—Relationship of faults as exposed on the north side of Brocks Gap.

WESTERN PART OF COUNTY

Northwest of Little North Mountain one of the major folds is sharply folded, involves several formations at the surface, and is well reflected in the topography, whereas others are gently folded, involve only one or two formations at the surface, and have relatively little topographic expression. In some folds surface observations indicate that the axial plane is vertical or nearly so, but in other folds the axial plane is distinctly inclined. The general trend of the folds is northeast-southwest but the fold axes are not everywhere parallel and the axes of some of the folds are curved. The major folds in this part of the county are, from east to west, the Supin Lick syncline, the Adams Run anticline, the West Mountain syncline, and the Bergton-Crab Run anticline (Young and Harnsberger, 1955, p. 325). The surface rocks are mostly Devonian and Mississippian sandstones and shales but one anticline, the Adams Run, has Ordovician and Silurian rocks exposed in the central part of the fold.

SUPIN LICK SYNCLINE

According to Young and Harnsberger (1955, p. 327) the Supin Lick syncline is entirely in Virginia and extends southwest from Columbia Furnace, Shenandoah County, to near Brocks Gap, Rockingham County, a distance of about 25 miles. Only the southwestern 6 miles or so are in Rockingham County. In the area of the southwestern plunge of the syncline the topography gives the impression that the southeastern part of the fold is cut off by a fault. On the western side of the fold a ridge of Chemung sandstone trends southwest, is bent toward the southeast in the area of plunge, and ends abruptly near the northwestern foot of Little North Mountain. There is no ridge on the southeastern flank of the fold corresponding to the ridge on the northwestern flank. In their description of this syncline, Young and Harnsberger (1955, p. 327) wrote: "Although the overall plan of the Supin Lick syncline indicates simplicity and structural regularity, the opposite is true in many places. Dips on the east limb range from normal through vertical to strongly overturned, depending on the proximity of the east limb to the North Mountain fault. Low dips predominate on the west flank of the syncline, along which minor normal faults are common locally." In the opinion of the present writer the strong deformation on the southeastern flank of the fold is probably accompanied by faulting. Further, the close approach of the Chemung and Millboro, with the resultant narrowing of the Brallier near the Shenandoah County line, suggests that some of the Brallier is missing. A northeast trending fault of relatively small displacement is probably present in the shales between the southeastern side of the Supin Lick syncline and the rocks of Little North Mountain. This fault (?) may have been caused by a westward shove by Little North Mountain during movement along the Little North Mountain fault. Normal faults on the west flank of the syncline appear to have formed late in the structural history and probably represent relaxation of the compressive forces that caused major deformation (Young and Harnsberger, 1955, p. 327).

ADAMS RUN ANTICLINE

The Adams Run anticline is a long fold of which only the southwestern 10 miles are present in Rockingham County. The projected strike of the fold extends into the west side of Little North Mountain but the anticline stops by plunging a few miles south of Fulks Run. In Rockingham County the fold is an anticlinal mountain, the highest part of which is along the axial portion of the fold. Dips in the Ridgeley sandstone along the west flank are commonly somewhat steeper than those on the east flank, indicating that the axial plane may be inclined toward the east. According to Young and Harnsberger (1955, p. 326): "The Adams Run anticline is much tighter and much less complex than either the Bergton-Crab Run anticline or the West Mountain syncline. The flanks of the anticline are steep, and although some drag folds are present they are not comparable in size or number with those of the more westerly folds. The symmetry of the limbs is broken only by a minor double fold on the eastern flank, north of Fulks Run." The Millboro-Onondaga occurs on the flanks of the anticline and the central portion of the fold has been eroded down to the Martinsburg shale near the northern border of the county.

WEST MOUNTAIN SYNCLINE

This structure extends completely across the county in a northeast-southwest direction. The axis of the fold is curved and is much nearer to the Little North Mountain fault in the southern part of the county than in the northern part. The lithology and structural characteristics of the fold change along the strike and many minor folds and faults occur in the axial region and on the flanks. In the northern part of the county the Chemung occurs in the axial area of the syncline and the dips on the limbs are commonly gentle. Toward the south the Hampshire occurs in the central part of the fold for a short distance and then the axial region contains Pocono beds to the Augusta County line. In the northern and central parts of the county where Little North Mountain is between the syncline and the Little North Mountain fault, the east flank of the syncline dips to the west. South of the southern end of Little North Mountain, the eastern flank of the West Mountain syncline is overturned and dips to the southeast. This overturned limb forms a prominent ridge, Narrow Back Mountain, from Rawley Springs south to Augusta County. Apparently the beds on the east flank of West Mountain syncline are overturned as a result of drag from movements along Little North Mountain fault where Little North Mountain is not present. Where Little North Mountain is present, the effects of drag are mainly confined to beds within Little North Mountain itself.

BERGTON-CRAB RUN ANTICLINE

This anticline extends south from West Virginia completely through Rockingham County, Virginia, and into Augusta County. The fold axis has a slightly sinuous pattern and roughly parallels the axis of the West Mountain syncline to the east. In the southwestern part of the county the low flank dips and the presence of small folds on the flanks make it difficult to locate the axis accurately. In this area the surface rocks involved in the folding consist of a wide expanse of Hampshire beds and a little Pocono sandstone. In the northern part of the county the flank dips are steeper than to the south and the axial region of the fold is occupied by the Chemung and Brallier formations with a small area of Millboro shale exposed about 2 miles west-northwest of Bergton. Young and Harnsberger (1955, p. 326) found a number of small fold axes, generally paralleling the major fold axis, in the axial area of the major fold, and three relative cross-folds on the east limb of the major fold which are expressed on the geologic map as embayments in the Brallier-Chemung contact. They suggested that the cross-folds are more apparent than real and probably result from doming along the major fold axis. In their description of the structure they say that: "Bedding dips vary greatly from place to place on the flanks of the major fold, but nowhere are the limbs overturned at the surface. However, the axial plane may dip strongly southeastward at depth. Drill-hole data and the attitude of minor surface folds indicate that the "Oriskany" and adjacent units may be faulted at depth. If faults are present, they are probably steep reverse faults which die out upward into minor anticlines."

AGE OF FOLDS AND FAULTS

The youngest rocks in the county involved in major faulting are of Devonian age and the youngest rocks involved in folding are Mississippian. In the absence of younger bedrock locally it is impossible to date accurately the time or times of deformation. There is no good evidence in the county to suggest appreciable deformation during the Taconic revolution at the close of the Ordovician or at any other time prior to the major formation of the Appalachians. Aside from the Precambrian, it is assumed that almost all deformation of the area took place during the Appalachian orogeny, principally toward the close of the Paleozoic Era. The deforming forces were probably directed from the southeast toward the northwest, as indicated by the prevailing southeasterly dips of the major faults and by the southeastern inclination of the axial planes of many major folds. The northwesterly inclined fault planes and northwesterly dipping axial planes of some folds probably resulted from local rather than regional causes.

The sequence of events indicated by major folds which have been cut by major faults, and by klippen and folded fault planes is: folding, faulting, and then a second stage of folding. The folding of fault planes was accomplished mainly during the second stage of folding, and it was at this time that certain areas were depressed and now remain as klippen. The northwest dipping reverse fault at Brocks Gap was probably formed after the beds were vertical or in their present overturned position. If the forces came from the northwest, then overthrusting is indicated; if the forces came from the southeast then it is a case of underthrusting. In regard to the formation of northwest dipping reverse faults in southwestern Virginia, Miller and Fuller (1954, pp. 264-265) wrote: "Stress of this type would develop normally during overthrusting as the moving block formed a monoclinal wrinkle, whereas folding of the monocline either before or after thrusting would not be expected to produce reverse faults upthrown on the northwest. The mechanism is related to underthrusting . . . " Following this analysis, the faulting at Brocks Gap would be of the same age as the major deformation of the area.

GEOLOGIC HISTORY AND DEPOSITIONAL SUMMARY

Rockingham County has bedrock ranging in age from Precambrian to the Mississippian Period of the Paleozoic Era. The geologic history of this span of time can be deduced only from whatever information can be extracted from these rocks. Precambrian rocks, mainly igneous and metamorphic, furnish relatively little information; the younger rocks, mainly sedimentary, yield considerably more information. Triassic (?) intrusives, which are present in a number of places in the county, supply few facts regarding the history of Triassic times.

PRECAMBRIAN AND VERY EARLY CAMBRIAN (?) TIMES

At present Precambrian rocks crop out only in a relatively small area in the extreme eastern part of the county, in the Blue Ridge Mountains. The oldest rocks here, the Virginia Blue Ridge complex, consist largely of granodiorite and gneiss. The igneous and metamorphic rocks of the "complex" have undergone so much deformation and alteration that their original character generally cannot be determined. Some of the original material of the Virginia Blue Ridge complex may have been graywacke or arkosic sediment, and some may possibly have been calcareous sediments or even basic igneous rocks (Brown, 1958, p. 61).

During Precambrian time this material, which may have been part of a pre-Appalachian geosynclinal sequence, was deeply buried, deformed and metamorphosed, affected over wide areas by migmatitic and magnatic processes, and eventually changed into the Virginia Blue Ridge complex. Following the orogeny that probably accompanied and caused these alterations, the area was subjected to secular erosion.

In either Late Precambrian or Early Cambrian time deposition of sedimentary material took place on this erosion surface. These clastic sediments make up what is known as the Swift Run formation. Brown (1958, p. 61) suggested that deposition of Swift Run material took place during what was probably an early stage in the development of the Appalachian geosyncline. The nature of the material suggests that deposition occurred in an environment that was near the shore-line; part of the formation may be of terrestrial origin and part shallow marine. The presence of greenstone in the Swift Run shows that volcanic activity occurred during deposition of the formation. This volcanic activity probably represents the very early stages of the volcanism which later produced the overlying Catoctin greenstone. In Late Precambrian time or Early Cambrian time, there was an extrusion of Catoctin volcanics in many parts of the Blue Ridge and Piedmont areas (Bloomer and Bloomer, 1947), and evidence for this in Rockingham County is found in the altered basaltic lava of the Catoctin greenstones. Pyroclastic rocks, sedimentary rocks derived from the same sources as the flows, accumulated along with the lava flows. Some intrusive bodies probably were emplaced at this time. The close of the Precambrian or very Early Cambrian is marked by uplift and erosion of these materials that resulted mainly from volcanic activity.

PALEOZOIC ERA

In early Paleozoic times an extensive area was subjected to depression and to eventual submergence. This depressed area was a long and relatively narrow trough that was the site of deposition of many thousands of feet of sediments during the Paleozoic. The trough extended at least from Alabama to Newfoundland in a northeast-southwest direction. The extent to the northwest is uncertain because the Cambrian rocks are deeply buried in that direction but information from deep wells indicates that the trough did not extend as far as central Ohio or central Kentucky. The southeastern boundary of this trough, or geosyncline, is not known because erosion has removed many of the products of deposition. The geosyncline did extend as far southeast as the Piedmont region, however, as proved by the occurrence of early Paleozoic rocks in that area. Most of the sedimentary material in the geosyncline came from the southeast so there must have been an area that was above water, at least part of the time, in that direction. Some have suggested that an extensive ancient landmass called Appalachia, now sunk beneath the waters of the Atlantic Ocean, was the source of the sediments that accumulated in the geosyncline. More recently it has been suggested that the source area was somewhat akin to a volcanic archipelago, and that the sediments were derived largely from volcanic islands. Whatever the source, the sediments were deposited in an area of subsidence. The downsinking of the trough may have been continuous or discontinuous but it approximately kept pace with the incoming material, so that all the thousands of feet of sediments that accumulated were deposited in relatively shallow water, less than 600 feet deep. Very probably the trough became filled with sediments from time to time so that the surface was above water-level, but renewed downsinking soon carried the surface of deposition below the water.

CAMBRIAN PERIOD

The earliest definite Cambrian rocks of the Appalachian geosyncline are chiefly coarse clastics, largely sandstones and closely allied types. The first formation to be deposited, and therefore the oldest, was the Loudoun, which in many places consists largely of sandstones, conglomerates, and some altered lava. According to King (1950, p. 16): "The Loudoun formation of the Elkton area is dominantly a slaty unit, probably largely of pyroclastic origin." The Loudoun materials accumulated on a surface of erosion that forms the present top of the underlying Catoctin greenstone. The Weverton and Hampton (Harpers) formations, which overlie the Loudoun, consist largely of sandstones, siltstones, shales, and conglomerates. The erosion of the source area to produce the hundreds of feet of sediments which comprise these formations probably lowered the old land area considerably. A rejuvenation, caused by uplift, probably occurred to give the streams the added velocity necessary to transport the clean coarse sand that makes up the Erwin (Antietam) quartzite. The oldest fossils in the county, *Scolithus*, occur in this formation and they are thought to represent borings by ancient worms in the unconsolidated sand of the sea floor. In other places the Erwin contains fossils of brachiopod shells and fragments of trilobites, which offer additional evidence of life of the time. After deposition of the Erwin quartzite the source area probably was reduced to a low elevation and a change in sedimentation occurred. Conditions favorable to carbonate accumulation led to the deposition of the dolomite and limestone of the Shady (Tomstown) formation. Very likely at this time the sea was warm and clear and highly charged with carbonates of calcium and magnesium. Following deposition of the Shady dolomite, there was a resumption of clastic sedimentation, this time accompanied by red mud which represents a new type of material in the Appalachian geosyncline. These clastics, together with the red mud, have been lithified to make a body of rock that is now called the Rome (Waynesboro) formation. The return to clastic sedimentation suggests that the land that was low-lying during Shady time was raised somewhat, and the invigorated streams transported small clastic particles and deposited them in the geosyncline. Beds of limestone and dolomite, which occur in the formation in places, suggest that locally there were changes in the environment to conditions that were characteristic of Shady time. Many of the beds of rock in the Rome formation show abundant ripple marks and mud cracks attesting to the very shallow water conditions under which the material accumulated. Apparently, after deposition of the Rome, the source area remained low for a considerable length of time, and thousands of feet of mainly limy material were deposited on the shallow sea floor. This lithified material is divided into several formations, some of Cambrian age and some Ordovician, each with its own particular variations. The Elbrook dolomite, which immediately overlies the Rome, consists mainly of dolomite, with some limestone and some thin beds of shale. Next was deposited the Conococheague, which consists principally of massive limestone beds with subordinate layers of dolomite. At times, during deposition of the Conococheague, the source area furnished quantities of medium-grained quartz sand which now form the sandstone beds that are characteristic of the Conococheague and serve to distinguish the formation from the other carbonate formations above and below. Deposition of the Conococheague limestone concluded the depositional history of the Cambrian Period.

ORDOVICIAN PERIOD

The close of the Cambrian is marked by an erosional interval in many parts of the world, but in much of the Appalachian area there seems to have been continuous sedimentation from the Cambrian into the Ordovician. The oldest Ordovician formation, the Chepultepec limestone, consists mainly of limestone with some beds of dolomite. The character and thickness of the Chepultepec are variable, indicating that different conditions existed in various parts of the area of accumulation at various times. The Chepultepec limestone encloses nodules of chiefly black chert similar to chert in the underlying Conococheague limestone. This siliceous material may have accumulated along with the enclosing limestone or may have replaced the limestone at a later date; possibly the chert is of different ages in different places. Next the Beekmantown formation, which consists chiefly of dolomite with subordinate limestone, was deposited. In places an intraformational conglomerate or breccia occurs at or near the base of the Beekmantown indicating that the depositional history of the early part of the formation was marked by uplift and erosion of a minor nature. The formation contains much chert, some of which may be primary and accumulated along with the enclosing limy material, but much of it is clearly secondary and was formed by replacement of the carbonate rock. The Beekmantown has extensive areas of outcrop in the county, and the relative constancy of the character of the formation suggests that conditions were fairly uniform during Beekmantown time. The top of the Beekmantown is marked in places by an unconformity, caused by uplift of the beds above sea level and erosion.

The Beekmantown is directly overlain by the dense pure, high-calcium New Market limestone. In places the contact between the

Beekmantown and New Market appears to be gradational as beds of New Market lithology occur interbedded with the upper beds of Beekmantown dolomite. Conditions favoring deposition of pure limestone must have existed for varying lengths of time as Beekmantown time drew near a close. Commonly the pure limestones of the New Market are overlain by dark, medium-coarse, cherty limestones of the Lincolnshire. In places, however, lenses of typical Lincolnshire lithology occur well down in with beds of typical New Market lithology and beds or lenses of typical New Market lithology may occur interlayered with limestones of characteristic Lincolnshire lithology. Apparently fluctuating environmental conditions resulted in the different lithologies. The rows of bedded black chert that so commonly occur along bedding planes in the Lincolnshire suggest that at times sizeable areas of the sea floor were covered with accumulations of siliceous material. In many places in the county the next material to be deposited was dark mud containing much organic matter. This consolidated material, at the base of the Edinburg formation, is now a black graptolite-bearing shale that commonly overlies the Lincolnshire. The change from carbonate accumulation to shale deposition suggests a slight uplift in the source area of the sediment. However, the shale deposition probably occurred in fairly quiet, possibly even stagnant water and there are layers of limestone interbedded with the shale showing that conditions favoring carbonate deposition were still present. During Edinburg time conditions of sedimentation varied in different parts of the county. In the vicinity of Massanutten Mountain chiefly black shale, siltstone, and interlayered thin-bedded black limestones were deposited, whereas in the vicinity of Harrisonburg the black shales are a distinctly subordinate part of the formation and occur mainly toward the base. On top of the black shale are hundreds of feet of dense, dark limestone that makes up the bulk of the formation. The upper part of the Edinburg contains some silty layers that indicate a change from the conditions favoring limestone deposition. Also, thin layers of altered volcanic ash, "bentonite", are present and have been traced for many miles. There was then some volcanism that resulted in small particles of volcanic material being carried into the air and settling over extensive areas of the Appalachian geosyncline. These volcanic ash layers are valuable time markers since a single layer was deposited over a large area at essentially the same time. The locations of the ancient volcanoes that produced the layers of volcanic ash are unknown, but presumably they were somewhere in North America.

The change toward clastic sedimentation which began in upper Edinburg time continued on into Martinsburg time. In places the base of the Martinsburg consists of interbedded dark limestones and dark shales, but most of the Martinsburg consists of shales, some of which are calcareous, and silty shales. It is likely that the source area of the sediments, while not very high, was at least higher than it had been for millions of years preceding. The close of Martinsburg time probably was marked by a renewal of uplift in the source area, as suggested by the thick deposits of medium-grained sandstone that occur in the upper Martinsburg. The presence of the marine brachiopod, *Orthorhynchula*, proves that this sandstone accumulated under water. The Oswego sandstone was deposited under decidedly different conditions from those prevailing during deposition of the Martinsburg shale. The Oswego was formed by firm consolidation of non-fossiliferous moderately course-grained quartz sand. It is not a cleanly washed sand and the presence of impurities may be inferred from the prevailingly dark color. Butts (1940, p. 486) has suggested that an uplift of the Canadian shield in the vicinity of the Great Lakes gave rise to sediments which were carried southward by rapidly flowing streams and deposited in central Pennsylvania. Sea currents picked up some of the sand in Pennsylvania and brought it southward to Virginia to form the Oswego sandstone in that locality. In Rockingham County the areas of exposure of the formation are so small, and those along Little North Mountain relatively so inaccessible in most places, that little can be learned about the depositional history of the formation. West of Little North Mountain the Oswego is buried below younger rock everywhere except in the axial region of the Adams Run anticline; east of Little North Mountain it has been removed by erosion, if it was ever present. The formation never extended as far east as Massanutten Mountain because in that area Silurian beds lie directly on top of the Martinsburg shale. The eastern shore-line during Oswego time lay somewhere between the present-day positions of Little North Mountain and Massanutten Mountain. In Rockingham County the distribution of the Juniata coincides with that of the Oswego. The Juniata probably represents deposition in fresh water (Butts, 1940, p. 487).

SILURIAN PERIOD

The Clinch (Tuscarora), which overlies the Juniata, is probably a nonmarine beach sand and pebble type of deposit. The formation is devoid of fossils in the county except for some possible worm borings. The Clinch is exposed in a single belt in Little North Mountain and in the

Adams Run anticline; it is buried beneath younger beds in other areas west of Little North Mountain The presence of the lithologically similar and partly equivalent Massanutten sandstone in Massanutten Mountain indicates that the formation once extended that far to the east. The Clinch sandstone has been removed by erosion everywhere east of Little North Mountain, except in the area of Massanutten Mountain.

Deposition of the overlying fossiliferous Clinton represents a change to marine conditions, at least during part of Clinton time. Lenses of sandstone in the Clinton which strongly resemble the Clinch sandstone probably indicate nonmarine environmental conditions. Marine fossils, especially ostracodes and a few species of trilobites and brachiopods, are common in much of the Clinton. The formation contains "fossil" iron ore from New York to Alabama, but no significant quantities of this well-known material are present in Rockingham County. The outcrop and extent of the Clinton in the county are essentially the same as for the Clinch.

The extent of the rocks belonging to the Cayuga group is essentially the same as that for the older Silurian formations; the most accessible exposures occur in the Adams Run anticline and in Little North Mountain and to a lesser extent in Massanutten Mountain. The earlier Cayugan deposits in the Massanutten area are of largely non-marine red sandstones and shale but later deposits contain fossiliferous shaly limestone. Rocks of Cayugan age in and west of Little North Mountain are not well-known in detail, but fairly thick deposits of fossil-bearing marine limestones are know to occur.

DEVONIAN PERIOD

The Devonian Period in Rockingham County began with the deposition of the Helderberg group, which consists largely of fossiliferous marine limestones with some shale. Some of the limestones of this group contain abundant bedded chert that probably represents deposits of siliceous material that accumulated on the old sea floor. The sea of Helderberg time apparently covered the county west of Little North Mountain, but it is not known how far the sea extended to the east. Deposits of Helderberg limestone have been noted in Massanutten Mountain but they are not clearly discernible in that part of the mountain which is in Rockingham County. The succeeding formation, the fossiliferous and calcareous Ridgeley (Oriskany) sandstone clearly was deposited under marine conditions. The extent of the Ridgeley sea apparently roughly paralleled that of the Helderberg sea. The presence of marine fossils in the Millboro and Onondaga rocks proves that they were deposited in salt water. In Rockingham County this sea covered the area west of Little North Mountain and extended as far east as Massanutten Mountain but erosion has removed the deposits between Little North and Massanutten mountains. Altered volcanic ash material has been reported from the Onondaga in wells drilled in the western part of the county (Young and Harnsberger, 1955, p. 324). If the identification proves to be correct, it shows that volcanic activity occurred during deposition of the Onondaga, but the location of volcanoes is unknown. The Millboro fauna consists principally of a typical black shale assemblage, suggesting that in the area of accumulation of the shale the sea was quiet or stagnant. The sparsely fossiliferous marine Brallier shale overlies the Millboro and indicates a change in environmental conditions. In Rockingham County the Brallier occurs only west of Little North Mountain, but regional relations suggest that the source was probably many miles to the east. The scarcity of fossils in the Brallier indicates that the environment of deposition was not conducive to abundant marine invertebrate life. The Chemung occurs in extensive outcrops west of Little North Mountain but its possible former extent in the county is unknown as erosion has cut below the Chemung horizon in the eastern part of the county. The Chemung is transitional with the Brallier, suggesting that no great changes took place in the source area until well after the beginning of Chemung time. The break between the formations is made on a faunal basis; the occurrence of fairly abundant large marine invertebrate fossils marks the contact at the base of the Chemung. Gradually, the sedimentary materials that make up the Chemung became coarser, and the presence of thin bands of conglomerate suggests a substantial uplift in the source area. The Chemung sediments probably were carried by currents north and south from an area in central Pennsylvania and the deposits may be compared with a long series of coalesced deltas (Butts, 1940, p. 494). Gradually the water became more shallow and the animal life disappeared and the Chemung sediments graded upward into Hampshire sediments.

The red sandstones and shales of the Hampshire formation crop out extensively in the county west of Little North Mountain. In Virginia the formation generally is devoid of marine fossils although fossil zones have been reported recently. The area of accumulation probably was below sea level for short periods of time but was mostly above the level of the sea and commonly was dry land. Hampshire sediments probably represent a deltaic type of deposit and Butts (1940, p. 495) suggested that the scene probably consisted of: " . . .a low subsiding coastal plain perhaps dotted with fresh-water lakes."

MISSISSIPPIAN PERIOD

The only indicator of Mississippian conditions in the county is the Pocono sandstone, and the present outcrops are all west of Little North Mountain. The main fossil material found in the Pocono in Rockingham County consists of fragments of land plants, some of which have been altered to coal. The environment of deposition of the Pocono probably was dry land on which fresh-water lakes existed at various times.

POST-MISSISSIPPIAN TIME

It is likely that deposits of Mississippian age younger than the Pocono were made in the county and deposition probably took place during the Pennsylvanian and Permian, but all these deposits have been removed by erosion.

Initial movements, preceding the later mountain-building movements, probably occurred in the Appalachian trough during the Pennsylvanian Period. The Permian Period was a time of considerable movement and of deformation of all the rocks in the Appalachian geosyncline. The earlier mainly downsinking movements were reversed during the Permian and the rocks were squeezed by horizontal forces, pushed toward the northwest, and upraised. Most of the folds, faults, and other secondary structures of the Paleozoic rocks, and probably some of the secondary structures of the Precambrian rocks, were formed at this time. The forces that caused this Appalachian orogeny, or mountain bulding, are of unknown origin but they were active for a very long time. As the land was uplifted the agents of weathering and erosion were active at the surface and began to destroy the previously deposited rocks. No one can say definitely that a sizeable mountain range was developed as a result of the Appalachian orogeny. Mountainous topography may have been present, but if erosion kept pace with uplift then no significant elevations of the land surface would have existed.

MESOZOIC ERA

Rockingham County has a number of igneous dikes, sill-like bodies, and one plug, all of which are assumed to have been emplaced during the earliest period of the Mesozoic, the Triassic. Other than this the geologic record suggests that erosion was the dominant process active in the county during the Mesozoic Era. It is possible that during the Mesozoic erosion was able to produce a peneplain, a gently rolling or undulating topography, that was probably not far above sea level and had a gradual slope toward the sea. If such a condition did exist then the rate of erosion would be very slow and it would take an extremely great length of time for any further lowering of the land to take place. If a peneplain was produced, subsequently the land was raised in a vertical direction, by forces of unknown origin, and erosion once again would become active and vigorous. In such a manner mountainous topography might have developed from an uplifted and dissected peneplain.

CENOZOIC ERA

The county probably has been above sea-level throughout most or all of Cenozoic time. It is possible that peneplanation or partial peneplanation followed by uplift may have occurred one or more times. Fairly late in Cenozoic time continental glaciation was a significant and widespread event in North America. The ice sheets, which had their origins in the Canadian region, moved outward radially from the areas of accumulation and in the eastern United States reached as far south as Pennsylvania. Although Rockingham County was not covered by any of these ice sheets, undoubtedly such things as the climate, the streams, and erosion and sedimentation were affected. Some of the gravel deposits in the eastern part of the county, in the vicinity of the South Fork of the Shenandoah River, were probably deposited during the Pleistocene, or Ice Age. Recent events with relatively minor modifications, have probably consisted principally of erosion of the uplifted land.

GEOMORPHOLOGY

Rockingham County lies within two physiographic provinces, the Blue Ridge and the Ridge and Valley province which includes the area of the Great Valley (Fenneman, 1938, p. 123). The area within the Blue Ridge province is relatively small and extends westward from the top of the Blue Ridge Mountains. The county extends completely across the Great Valley (Shenandoah Valley), which is here about 20 miles wide, to the crest of Shenandoah Mountain, a prominent ridge of the Ridge and Valley province. The Valley east of Massanutten Mountain is about 5 miles wide and the Valley west of Massanutten is about 12 miles wide.

Several different interpretations of the history of landforms in the Appalachians have been made and there has been a lack of general agreement on the number and ages of erosion surfaces preserved. A chart compiled by King (1950, p. 53) shows some of the various interpretations (Table 3).

Many writers have suggested that the Appalachian region was reduced by erosion to a peneplain one or more times. That is, after the Appalachian Mountains were formed erosion attacked the rocks and slowly cut the area down to a nearly flat plain. The surface would be gently rolling, not far above sea-level, and would slope gradually toward the sea. On this "near-plain," or peneplain, would be some residual high areas called monadnocks. After uplift, streams would cut new valleys and the tops of the hills would be remnants of the old peneplain. Such a cycle might run its course several times and each peneplain would be represented by even-crested ridges of approximately the same elevation.

Evidence from the county may be cited in favor of the existence of one former peneplain, now represented by elevations generally above 3,000 feet. On the other hand, the evidence for even one peneplain is not compelling and present topography may be interpreted as the result of secular weathering and erosion of rocks of varying resistance, thickness, and structure.

INTERPRETATION OF LANDFORMS

Some of the more salient landforms which have resulted from differential weathering and erosion of different types of materials and structures are discussed briefly below.

TABLE 3.—*Interpretations of land forms in Appalachians of Virginia (Modified after King, 1950)*

Topographic Position	A. Keith, 1894 pp. 336-394	D. Johnson, 1931 pp. 14-21	F. J. Wright, 1934, pp. 1-43; 1925, pp. 7-41	A. J. Stose and G. W. Stose, 1946 pp. 6-10; G. W. Stose, 1940, pp. 461-476	P. B. King 1950, pp. 52-63
Above summits		Fall Zone peneplain; pre-Cretaceous		Rejected, same as Schooley peneplain	
Summits	Residuals on Blue Ridge		Residuals, no definite peneplain		
Uplands	Cretaceous or Catoctin base level; Cretaceous	Schooley peneplain, Middle Tertiary	Schooley peneplain	Schooley peneplain; pre-Cretaceous but not dissected until Miocene	Not studied, may be Mesozoic
Intermediate Surfaces	Weverton base level		Doubtful	Weverton peneplain (minor)	Doubtful in Elkton area
Valley Floor	Tertiary base level = pre-Lafayette surface; Late Tertiary	Harrisburg peneplain; Late Tertiary (?)	Harrisburg peneplain; or Valley peneplain	Harrisburg peneplain; Late Tertiary	Valley floor peneplain and residuum, older Tertiary
Below Valley Floor		Somerville peneplain	Part of Harrisburg surface		Ancient gravel unit: Tertiary (?)

BLUE RIDGE

Along the crest and northwest slope of the Blue Ridge the main rocks are Catoctin greenstone, Swift Run formation, and granodiorite. The resistant greenstones cap some of the higher hills, as Hightop, almost 3,600 feet in elevation, and in many places make high vertical cliffs. The western foot-hills are composed chiefly of Lower Cambrian clastic rocks which dip in a generally northwesterly direction. The thick resistant quartzites of the Erwin are prominent hill- and ridge-makers and form many of the hog-backs or cuestas of the northwest slope of the Blue Ridge. These quartzites extend from altitudes above

2,000 feet, Hanse Mountain for example, down to about 1,000 feet, at the northwest base of Giants Grave. The numerous quartzite talus slopes attest to the constant reduction in height of the quartzite mountains.

MASSANUTTEN MOUNTAIN

The high ridges of Massanutten are composed of the thick massive Massanutten sandstone that has been folded into a dominantly synclinal structure. The area between the ridges and the areas outside the ridges are underlain by shales and are topographically low. In the eastern two ridges in the county dips commonly are steep and elevations are mainly between 2,200 feet and 2,500 feet. At the southwestern extremity of the mountain where the two ridges meet, dips are lower than at other places and the mountain has an altitude greater than 2,900 feet. In the western two ridges elevations are commonly 3,000 feet or so and in the area of plunge, the elevation is more than 3,300 feet. There appears to be a definite relation between structure and the rate of lowering of the sandstone ridges of Massanutten Mountain.

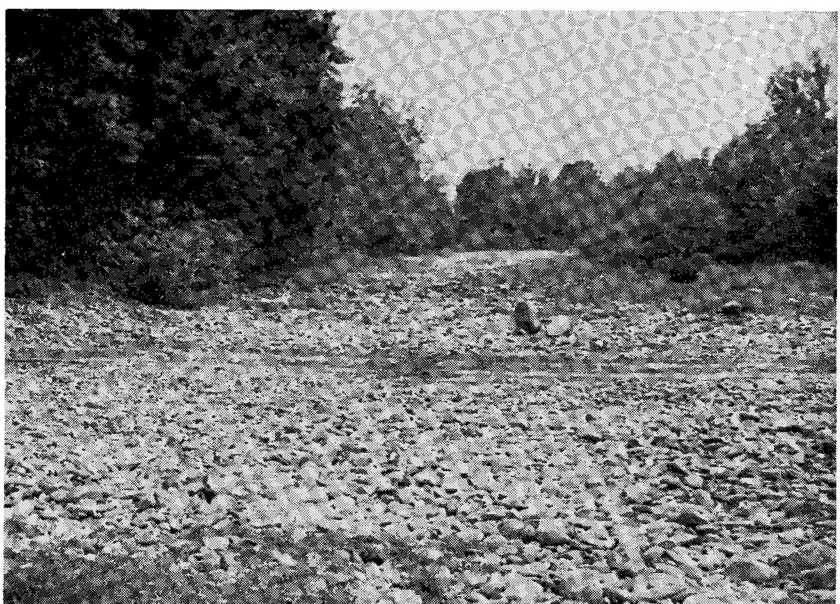
LITTLE NORTH MOUNTAIN

Little North Mountain commonly is capped by steeply dipping beds of sandstone of the Oswego-Juniata or Clinch formations. The relations are not altogether clear in all cases but the higher elevations commonly occur where the formations are thick and dips are relatively gentle. The lowest elevations, near the Shenandoah County line, are where the Oswego-Juniata is thinner than usual and the Clinch of no more than average thickness.

Brocks Gap, a water-gap cut through Little North Mountain by the North Fork of Shenandoah River, (Pl. 18A) is not related to either a thinning or to an increase in dip of the ridge-making sandstones of the mountain. An apparent off-set in the mountain at Brocks Gap makes it appear that there may be a cross-fault with left lateral displacement through the gap, but field evidence does not support the presence of such a fault. There is a cross-anticline with a west-northwest trend, at New Market Gap in Massanutten Mountain about 14 miles to the east, and two large folds, west of Little North Mountain, die out at approximately the latitude of Brocks Gap. Although no proof can be offered, it is possible that the northwestward extension of the cross-anticline partly controlled the plunge of the folds and also influenced the formation of Brocks Gap.

Plate 16

A. Fault on south wall of the Betts quarry east of Harrisonburg. Oe, Edinburg limestone above fault; Ob, Beekmantown dolomite below fault.



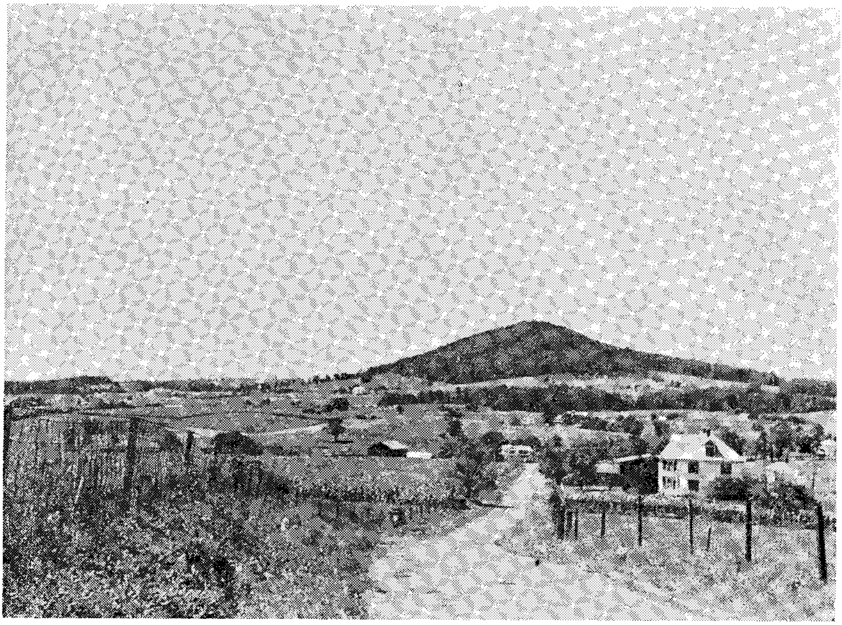
B. Bed of North River about 3 miles southwest of Spring Creek in in August, 1959.

Plate 16

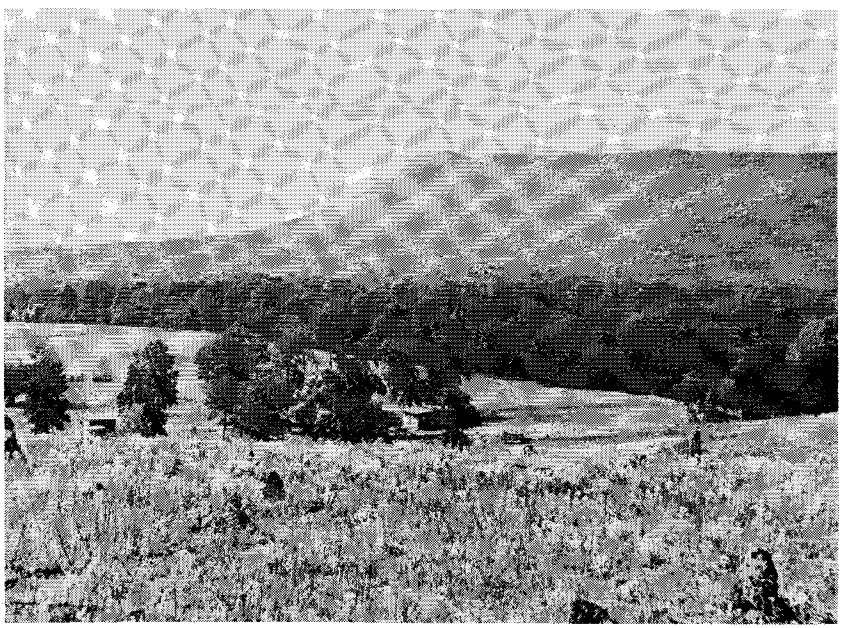
A. Fault on south wall of the Betts quarry east of Harrisonburg. Oe, Edinburg limestone above fault; Ob, Beekmantown dolomite below fault.

B. Bed of North River about 3 miles southwest of Spring Creek in in August, 1959.

Plate 17

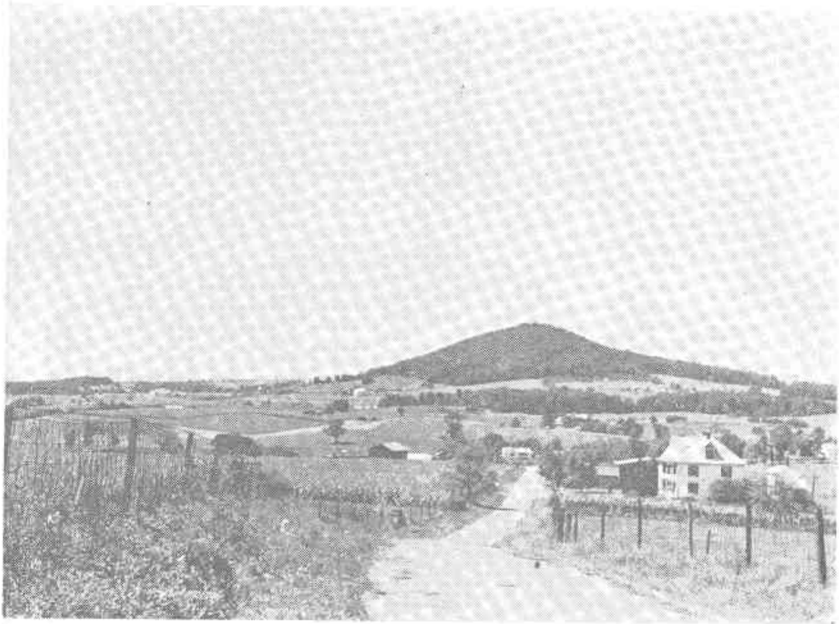


A. Mole Hill, plug of olivine basalt, about 4 miles west of Harrisonburg. View toward the west.

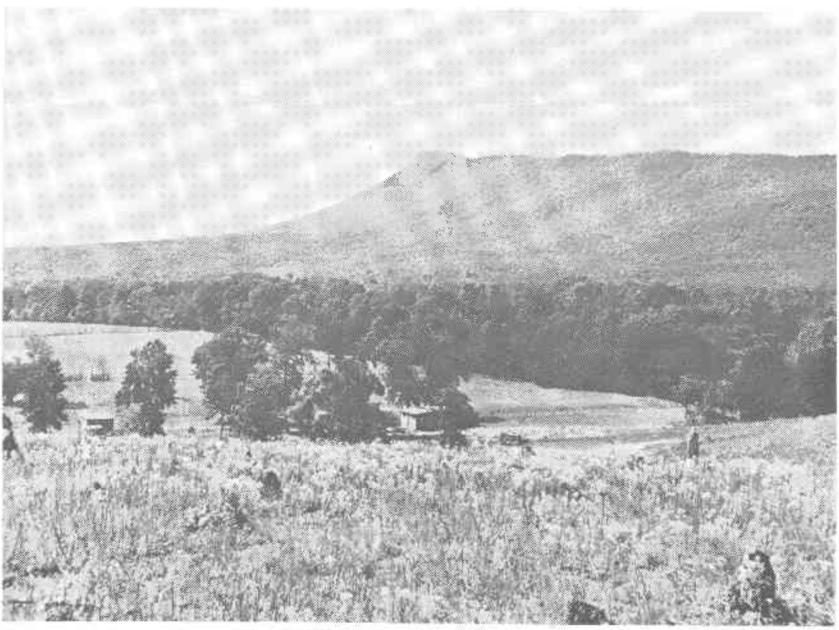


B. Southwestern end of Massanutten Mountain. View toward the west.

Plate 17



A. Mole Hill, plug of olivine basalt, about 4 miles west of Harrisonburg. View toward the west.



B. Southwestern end of Massanutten Mountain. View toward the west.

NARROW BACK MOUNTAIN

From an inspection of the topographic map Narrow Back Mountain appears to be a northwest off-set of Little North Mountain; however, the two mountains are quite dissimilar and were never connected. Narrow Back Mountain is formed by steeply dipping beds of Pocono sandstone on the southeast flank of an overturned syncline. Where Little North Mountain is between the Little North Mountain fault and the syncline, the east flank of the syncline dips normally to the northwest. Southwest of the extent of Little North Mountain the beds on the southeast flank of the syncline were moved to a steeply dipping to overturned position, apparently by drag along the fault.

SHENANDOAH MOUNTAIN

Only the crest and southeast side of Shenandoah Mountain are within the area of Rockingham County. The overall structure appears to be synclinal and along the crestal portion of the mountain are isolated remnants of Pocono sandstone which form some of the higher areas. On the east side of the mountain many of the high peaks are capped by outliers of mainly the lower part of the Pocono sandstone. In many places elevations of peaks suggest that the Pocono was eroded from the top a relatively short time ago.

CHURCH MOUNTAIN

Church Mountain is an anticlinal mountain outlined by ridges of fairly steeply dipping Ridgeley sandstone. The high central part is the axis of an anticline that is given topographic prominence by resistant sandstones chiefly of the Oswego-Juniata and Clinch formations. Elevations in the axial region near the Shenandoah County line reach more than 3,000 feet and the local relief is approximately 1,500 feet.

GREAT VALLEY

The central part of the county, the Shenandoah or Great Valley, is underlain chiefly by Cambrian and Ordovician limestones, dolomites, shales, and thin sandstones. Within this expanse are many minor topographic variations caused by differences of resistance of the rock and by structure. Chepultepec limestone is relatively weak and almost always occurs along or near the bottom of a valley. The cherty Lincolnshire forms many low hills and ridges. Northwest of Harrisonburg is a breached anticline outlined by ridges of cherty Lincolnshire, with the Beekmantown in the topographically low central region. North of Timberville is an anticlinal hill in which the central high area of cherty Lincolnshire limestone is surrounded by the Edinburg formation in a topographically lower position.

Concentrations of chert in the Beekmantown dolomite give rise to generally rounded hills up to several hundred feet high, as for example, Round Hill west of Bridgewater and Green Hill east of Singers Glen. Long relatively low ridges are commonly formed by thin sandstones in the Conococheague formation and the length of a continuous ridge may exceed 10 miles.

The north end of the Burketown klippe, west of Mt. Crawford, and the Dayton klippe, west of Dayton, are topographically high areas. The klippen contain Beekmantown dolomite and parts of other formations also, which are more resistant than the surrounding Martinsburg shale. Silicification along the Pulaski-Staunton fault, southeast of Harrisonburg, has given rise to a ridge that marks the approximate trace of the fault.

Mole Hill, about 4 miles west of Harrisonburg, is an igneous plug about 500 feet high. The olivine basalt that forms the plug is considerably more resistant than the surrounding Beekmantown dolomite.

CAVES

Caves and caverns are prominently advertised and are well-known features of the county. Most of the caves are in limestone (including dolomite) and were caused principally by solution of the limestone by subsurface water. Water in cracks in the limestone dissolves the rock and enlarges the openings resulting in sinuous underground passageways. These solution channels commonly are branching and many of the openings may extend for miles. The presence of caves commonly is indicated at the surface by sinks or sinkholes, some of which result from collapse of surface rock into an underground chamber or enlarged solution channel. Many caves have more than one level of passageways, much like floors or stories of a building, which may be connected by vertical openings. Caves are damp or wet from seepage by subsurface water, and one or more levels may be occupied by streams. In addition to dissolving rock to form caves, underground water usually deposits material to form stalactities, stalagmites, and other cave features. The commercial caves of the county, which may be visited by the public, are listed below.

MASSANUTTEN CAVERNS

Massanutten caverns are about ½ mile east of Keezletown. The cave entrance is in limestone of the New Market-Lincolnshire formation at the northwest foot of Massanutten Mountain near the southwest end of the Mountain.

MELROSE CAVERNS

Just west of U. S. Highway 11, about 6 miles northeast of Harrisonburg are the Melrose caverns. The entrance to the caverns is in a wide folded belt of New Market-Lincolnshire limestone. Many sink-holes and small caves are in the immediate vicinity.

ENDLESS CAVERNS

Endless caverns are about 3.5 miles south of New Market, Shenandoah County. The entrance is close to the contact between the Beekmantown and New Market-Lincolnshire formations on the west side of Massanutten Mountain. The caverns are along the axial region of a northeast plunging anticline and are a mile or two northeast of the northeastern end of the Pulaski-Staunton fault.

OTHER CAVES

The many non-commercial caves in the county vary considerably in size. The locations of the known caves in Rockingham County are plotted on Plate 2 and they are separated into two groups on the basis of size. The larger caves are large enough for shelter or storage of materials; the smaller ones are thought to be unsuitable for such purposes. Cave locations and information as to size were obtained from: D. C. Speleograph, published by the D. C. Grotto, a chapter of the National Speleological Society.

MINERAL RESOURCES

The mineral resources of Rockingham County include the ores of iron, manganese, copper, zinc and lead; limestone and natural gas. Some of the resources apparently have been exhausted, other currently are being exploited, and some show possibilities for the future. Mineral materials produced in the county in 1957 in order of value were: zinc ore, stone, manganese ore, and sand and gravel (Metcalf and others, 1958).

IRON AND MANGANESE ORES

BLUE RIDGE AREA

A recent investigation of the iron and manganese ore deposits has been made by P. B. King (1950) who discussed, in some detail, the deposits in the Elkton area on the west slopes of the Blue Ridge Mountains. Much of the following information has been extracted from that work.

Iron ore was mined in the Elkton area between 1836 and 1905 and an estimated 350,000 tons of concentrates were produced. Manganese ore and manganiferous iron ore were mined at times between 1884 and 1959, and it is estimated that more than 23,000 tons of concentrates were produced. Three of the major producing mines were located in Rockingham County just south of Elkton; these are the Kendall and Flick, the Neisswaner, and the mines of the U. S. Manganese Corp. The producing beds commonly are covered by thick gravel deposits and there are no reliable estimates of reserves available. Many of the old workings are inaccessible and recent prospecting has been restricted to small areas. The exposures and old workings that are accessible indicate only a small amount of ore. The easily located deposits of high-grade iron ore were exhausted long ago. In view of the large quantities of iron demanded by modern industry and the expense involved in opening a new mine, it would not be economically profitable to exploit the small deposits of iron ore that do exist in the area. In general, the deposits of manganese ores were operated on a smaller scale than were the iron ore deposits. The known deposits of high-grade manganese ore have been exhausted but a number of undiscovered deposits may exist. It is quite possible that future prospecting will discover deposits of manganese ores that can be worked at a profit.

The ore minerals in the iron and manganese deposits occur as oxides of iron and manganese. Weathering, acting near the surface of the earth, and solution by and deposition from ground water, formed these deposits by concentration and replacement. The important deposits occur in residual material from weathering of the Cambrian age Shady (Tomstown) and Rome (Waynesboro) formations. Traces of iron and manganese oxides occur as a film on the surface of some of the Early Cambrian siliceous formations, and in fault breccias in the area, but these occurrences are not likely to be of economic importance. Most of the ore deposits of iron and manganese are in residual material overlying the lower part of the Shady dolomite, but a few rich deposits are in residuum overlying the Rome formation. There are a few deposits in the residuum overlying the upper part of the Shady but such deposits are not common. Although the structural setting is quite variable most of the ore bodies are located in areas of homoclinal or synclinal structure.

The ore, which is embedded in clay, consists of iron and manganese oxides in the form of hard, spherical or botryoidal nodules ½ inch to 8 inches in diameter or in larger irregular masses. The ore nodules seem to be most common in silty clay and in some deposits the nodules occur in zones or layers separated by non-mineralized clay layers. The large masses of iron and manganese oxides usually follow the stratification of the enclosing clay but in places they cut across the lines of stratification. The iron and manganese oxides of the ore bodies occur in all proportions; deposits consisting principally of iron oxides are common and deposits of dominantly manganiferous iron ore also are common. Less common are deposits with a large amount of manganese oxides, but in some of the iron-ore deposits the proportion of manganese oxide may increase with depth. Varieties of limonite are the most common iron oxides, whereas the manganese oxides have been called psilomelane, pyrolusite, and manganite, but laboratory study is needed to identify the manganese minerals.

Many studies have been made concerning the origin of the iron and manganese ore deposits along the western edge of the Blue Ridge and some of the earlier workers thought the deposits represented original beds that had been considerably weathered. Harder (1910, pp. 100-101) expressed the opinion that the manganese was dissolved from overlying beds, carried downward by percolating waters, and deposited in certain favorable places. A favorable place might be determined by an underlying impervious layer, such as quartzite, through which the water could not readily move. Later reports (Stose and others, 1919, pp. 54-55 and Stose, 1942, pp. 163-172) also discussed the problem of the origin of these ores. Stose (1942, pp. 166-167) concluded: ". . . that manganese and iron-bearing minerals were originally disseminated in calcareous sediments near the contact between the dolomite and limestone and the underlying quartzite of the Lower Cambrian series; that the minerals were dissolved by meteoric waters during the weathering of the rocks at the surface; and that manganese and iron oxide were redeposited by these waters in the clays residual from the sedimentary rocks and in overlying gravel and wash. The unweathered carbonate rocks that directly overlie the quartzite and contain the disseminated manganese mineral from which the ore deposits were derived are nowhere exposed in central and northern Virginia, owing to their deep weathering and the heavy mantle of mountain wash that conceals them; hence the original source beds have so far not been found."

Most observers agree that compounds of iron and manganese existed as part of the original sedimentary material. Observations in northeastern Tennessee on the unweathered rocks equivalent to the Shady and Erwin formations of northern Virginia lend support to the idea that the manganese was probably a disseminated carbonate constituent of the original rock (King, 1950, p. 66).

The iron-ore deposits of the Blue Ridge area are of less relative importance than the manganese ores, therefore the question of their origin has received less attention. King (1950, p. 66) suggested that the iron may have been a primary constitutent of disseminated carbonate in the Shady, or in some places may have been derived from pyrite and other minerals of hydrothermal origin which occur in the local rocks. It is not known which of the materials accumulated first, but the manganese oxides may have formed somewhat later than the iron oxides (King, 1950, p. 66). The concentration of ores possibly took place during the formation of the enclosing residual clay. Some of the ore nodules have slickensides which were inherited from the clay which they replaced. Stose (Stose and others, 1919, p. 45) said that certain textural features: "... show conclusively that the nodules of manganese oxides have grown by replacing the clay substance in which they are embedded. There is, further, no evidence of the crowding back of the inclosing material such as would occur if the nodules had grown in the clay without replacing it."

MINES

Descriptions of the mines in the Elkton area which have produced iron or manganese ore were given by King (1943, 1950). His accompanying maps show the names and locations of the various mines as well as the locations of many prospect pits. Included below are brief descriptions of the mines in Rockingham County.

Fox Mountain Mine—This mine is on the north slope of Fox Mountain and is about 3½ miles northeast of Elkton (Pl. 1, loc. 17). It was first opened in about 1836, and was the greatest producer of iron ore in the area. During the main period of production between 1880 and 1890, 100 tons of concentrates per day were sometimes produced. Ore analyses, made between 1838 and 1886, were given by King (1950, p. 74). The long abandoned and overgrown workings of the mine cover nearly ten acres and consist of a branching open-cut, about 40 to 60 feet deep, the central part of which is filled with water. In the sides of the cut are exposed thinly-laminated reddish and brownish clay layers that are much folded and contorted. Only small amounts of iron oxides are now visible in the workings and it appears that the orebody was completely removed.

Elkton mines—The Elkton mines, which include the Kendall and Flick mine, the Neisswaner shaft, and the mine of the U. S. Manganese Corp. are about a mile south of Elkton on the northwest slope of Hanse Mountain. The first mining of manganese ore in the Elkton mines was about 1888 when about 36 tons of concentrates were produced by the Rockingham Manganese Mining Co. Kendall and Flick operated the mines intermittently until 1910. The total production of the mine is estimated at 10,000 tons of concentrates. The main workings, which are now caved and overgrown, were in residual clay overlying the lower part of the Shady dolomite, and consisted principally of a shaft 256 feet deep which connected to a tunnel, and of a long open cut. The deposits consist of a mixture of manganese and iron ores embedded in variegated clay (Harder, 1910, p. 57).

The Neisswaner shaft, 312 feet deep, was operated by the Pittsburgh Manganese Co. from 1910 to 1915. The total production of about 1,750 tons of concentrates was chiefly psilomelane which ranged in manganese oxide content from 46 to 50.5 percent. The main ore zone contained hard masses of manganese minerals as irregular bodies in soft variegated clay.

The U. S. Manganese Corp. operated in the area of the Elkton mines in 1916. Several thousand tons of concentrates containing 42 to 50 percent manganese oxide are reported to have been produced. The Elkton area has been well prospected and considerable ore has been produced, but no promising discoveries have been recorded in recent years.

Seller mine—The Seller mine is located a mile and a half southeast of Island Ford, a station on the Norfolk and Western Railway. Kendall and Flick opened the workings around 1900 by sinking a 60 foot shaft and making an open-cut. During about 6 months of the year 1941 the mine was worked and about three carloads of ore were shipped. The ore contained about 30 percent manganese and had considerable iron and phosphorus. In 1957 a small amount of manganese ore of 35 percent or more manganese content, was produced from this mine by Blue Ridge Mineral and Mining Co., Inc. (Metcalf and others, 1958). The Seller mine is in residuum overlying steeply dipping beds of the lower Shady dolomite.

OTHER IRON ORES

The term "Oriskany" ore has been applied to limonite deposits that occur in or near the Ridgeley (Oriskany) sandstone. The iron of this horizon is thought to have been disseminated in Devonian shale originally; then taken in solution from the shale and carried downward and deposited at a lower horizon. The outcrop areas of the Ridgeley (Oriskany) in Rockingham County are small, and throughout much of the extent along Little North Mountain the beds are vertical to overturned, hence the structure is unfavorable for deposition of ore as described above. The description by Holden (in Watson, 1907, pp. 433-434) of the Oriskany ores in Rockingham County suggests that he may not have known of the Ridgeley (Oriskany) sandstone in Little North Mountain and in the Adams Run anticline. The writer has seen many small old prospect pits near the base of Little North Mountain and has surmised that they were made in search for iron ore. Most of the prospect pits are along the east side of the mountain near the contact between the Oswego and Martinsburg formations, whereas the Ridgeley (Oriskany) sandstone occurs along the west flank of the mountain. No traces of iron ore or any other type of mineralization were seen in association with these pits.

The Clinton formation, which carries the well-known "fossil hematite" or "Clinton-ore," has small areas of outcrop in Rockingham County. The writer has seen iron ore associated with this formation in scattered areas along the top of Little North Mountain but there is no record that iron ore of this type has ever been mined in the county.

ZINC AND LEAD

A recent report by Paul Herbert and R. S. Young (1956) contains a discussion of sphalerite and other sulfide occurrences in Rockingham County and adjacent areas. Much of the following information was obtained from that publication.

Within the past ten years or so considerable prospecting, including core drilling, has been done in an effort to locate sulfide orebodies in the northern part of the Shenandoah Valley in Virginia. An area surrounding Timberville, Rockingham County, about 50 miles long and 25 miles wide, contains occurrences of zinc sulfides. The dominant mineral among the sulfides is sphalerite which most commonly is found in the upper Beekmantown formation. Minor shows of sphalerite have been noted in the Devonian shales and sandstones that occur in western Rockingham County. In 1950, three large zinc companies began intensive exploration programs and an orebody was found on the Bowers-Campbell property near Timberville. A zinc mine was opened on this property in 1957 by Tri-State Zinc, Inc. and has been in operation ever since.

MINERALOGY OF THE DEPOSITS

Sphalerite is the dominant sulfide of the district and the only one of economic importance. Of the other minerals that occur, galena, pyrite, chalcopyrite, greenockite, and fluorite; pyrite and greenockite are most widespread but commonly occur in small quantity. The color of sphalerite is variable but in a single locality a particular color is usually characteristic. The color differences probably are caused by variations in iron content; in general, a greater amount of iron results in a darker color. Disseminated grains or stringers of pyrite are present in all the mineralized areas, and galena occurs in several of the mineralized areas but not in economic quantity. Zinc carbonate is generally present in the zone of oxidation of mineralized outcrops.

The paragenesis, sequence of mineral formation, which probably holds for most places throughout the area is: dolomite, quartz, pyrite, galena, and sphalerite. The Timberville deposits are probably more closely allied with the low temperature barite veins of central Kentucky than with any other type (Herbert and Young, 1956, p. 15). The zinc and lead sulfides have their major occurrences in the district in association with: (1) recrystallized rock dolomite, (2) white vein dolomite as simple fracture fillings, and (3) white vein dolomite which cements breccias.

BOWERS-CAMPBELL MINE

The Bowers-Campbell mine is about 2 miles northwest of Timberville on the southeast side of State Road 881 between State Roads 614 and 789 (Pl. 18B). This area long has been known as a mineralized site and there are old diggings and an old shaft on the property. Following a period of successful prospecting, Tri-State Zinc, Inc., opened a zinc mine in April, 1957.

The ore occurs in a vertical breccia body cutting across Beekmantown dolomite beds that dip about 30° to the southeast. The breccia body is about 700 feet long, 100 feet wide, and extends to a depth of more than 700 feet. A bedding-plane thrust fault, at a depth of about 400 feet, offsets the upper part of the breccia body to the northwest. (Herbert and Young, 1956, Plate 12).

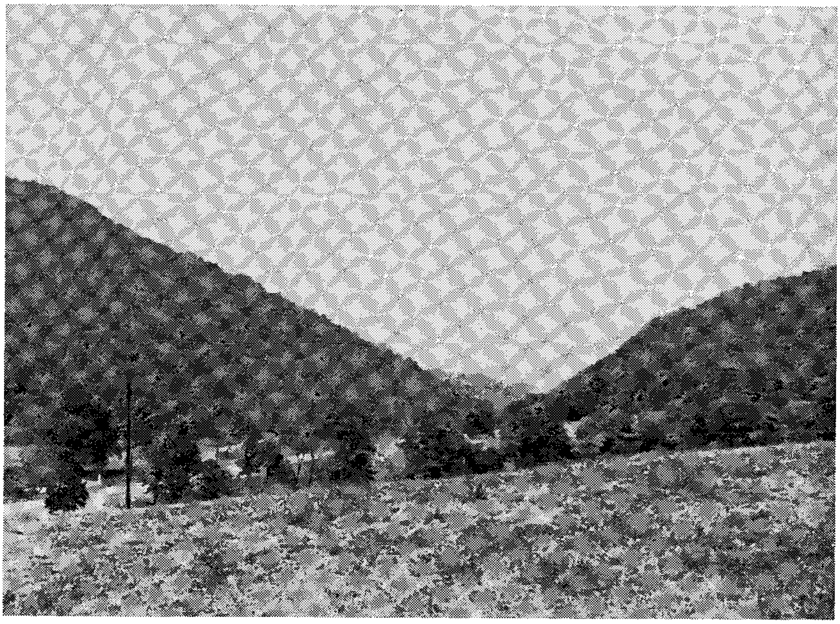
Mining and Milling—Sphalerite (ZnS) is the only mineral recovered but crushed limestone is sold to a nearby limestone quarry operator. A slight amount of galena (PbS) is present and some pyrite (FeS_2) and greenockite (CdS), but none of these occurs in sufficient quantity to be of value to the mining company. Smithsonite ($ZnCO_3$) has been reported from mineralized outcrops. The gangue minerals include white vein dolomite, quartz, and calcite.

Access to the mineral deposit is by an inclined adit 17 feet by 14 feet, which has at the present time, an underground length of about 4350 feet and a total vertical depth of approximately 475 feet. The adit is in the shape of an irregular spiral and an approximate ten percent grade is maintained throughout most of the length. About 30 men are employed at the mine. Mining operations are carried on for 8 hours a day but the mill is operated 24 hours a day. The method of mining employs the use of much heavy machinery and equipment underground. The ore is loosened by blasting, loaded into trucks by mechanical shovels, and hauled up the adit by the trucks and dumped into the ore-bin at the surface.

In the processing plant the ore moves progressively from the ore-bin to a primary (jaw) crusher, where it is reduced to ¼ inch size, sent to a rod mill, and to a rake classifier. The under-flow from the rake classifier moves to a ball-mill and then to floatation cells for recovery of the ore concentrate. The concentrate is trucked to Timberville and shipped by rail to a smelter at Josephtown, Pennsylvania. Mining operations yield about 50 tons of ore per man per month. The ore grade is approximately 5.5 to 6% and the concentrate contains about 60% zinc.

Ventilation is accomplished by pumping air into the mine down vertical shafts; the air leaves the mine through the adit. There is some water at and near the bottom of the mine but not enough to cause serious difficulties. Some of the mine water is used in drilling operations in the mine but much of the water is pumped to the surface and stored in an open pond for later use in the mill. Details of the mine and its operation have been described by Larry G. Hayes (1960), Mine Super-

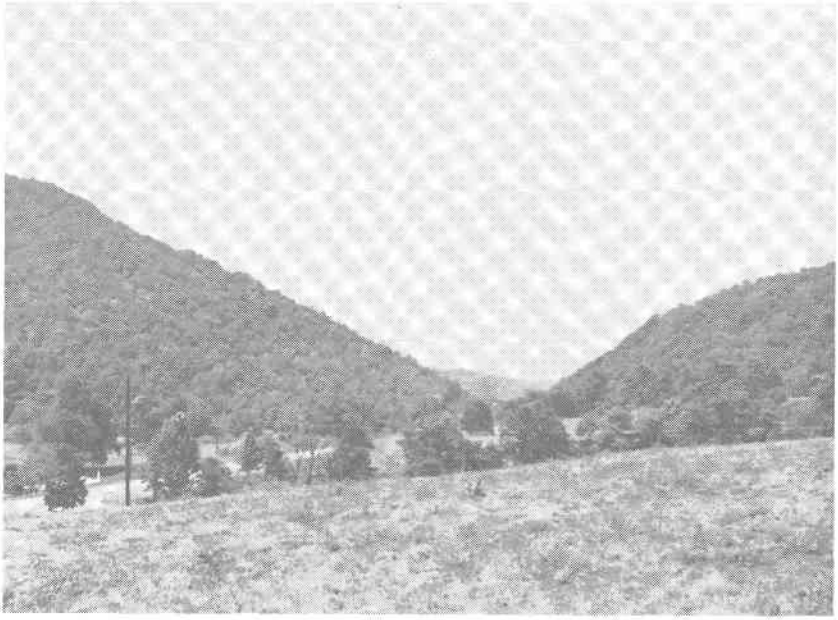
Plate 18



A. Brocks Gap, water gap of North Fork of Shenandoah River, in Little North Mountain. View toward the west.

B. Crusher, ore-bin, and mill of Tri-State Zinc, Inc. at Bowers-Campbell mine, Timberville.

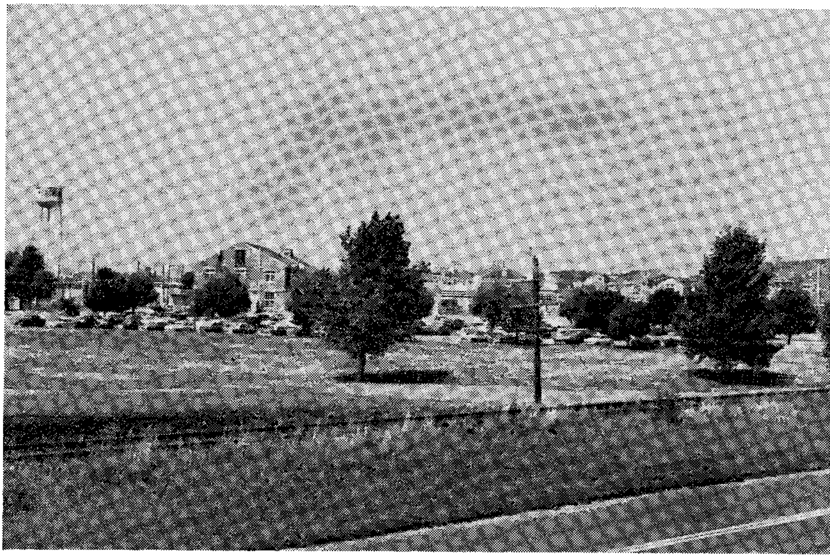
Plate 18



A. Brocks Gap, water gap of North Fork of Shenandoah River, in Little North Mountain. View toward the west.

B. Crusher, ore-bin, and mill of Tri-State Zinc, Inc. at Bowers-Campbell mine, Timberville.

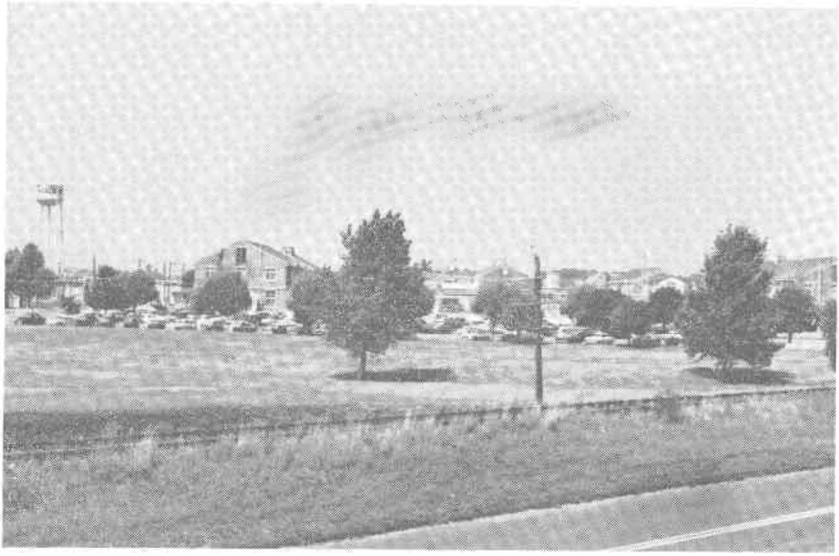
Plate 19



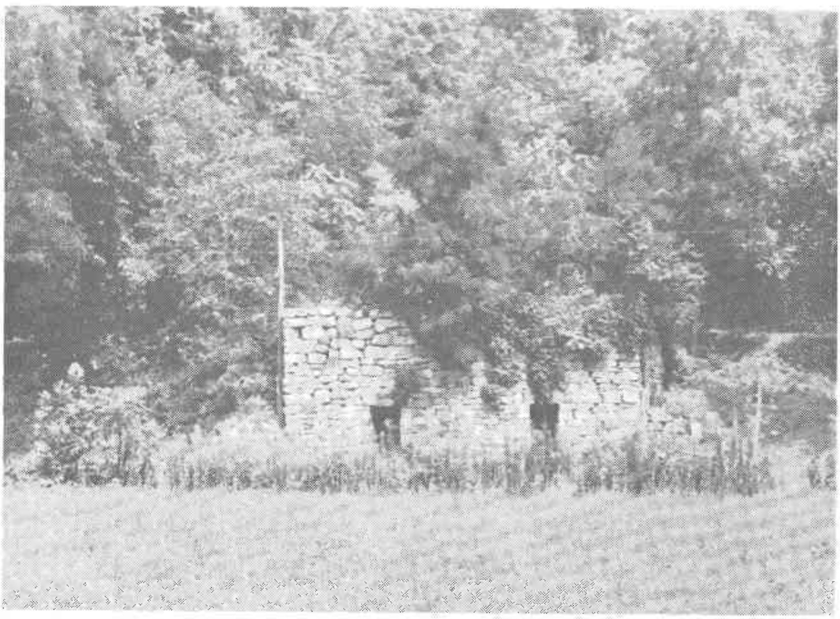
A. Stonewall plant of Merck and Co. about 2 miles south of Elkton.

B. Old lime kiln on Dry River about 2.5 miles southeast of Rawley Springs.

Plate 19



A. Stonewall plant of Merck and Co. about 2 miles south of Elkton.



B. Old lime kiln on Dry River about 2.5 miles southeast of Rawley Springs.

intendent-Engineer. Plate 3 shows the surface lay-out of the Bowers-Campbell mine.

VETTER PROPERTY

This property, about 2.5 miles southwest of the Bowers-Campbell mine, is about 1.5 miles northwest of Broadway, on the east side of State Road 789, 0.6 mile south of the intersection of State Roads 789 and 792. Sphalerite and pyrite occur in a breccia in the upper Beekmantown formation at approximately the same stratigraphic horizon as that in the Bowers-Campbell mine. There are several small mineralized outcrops which are fractured and brecciated, but the property has not been thoroughly prospected by drilling.

ARMENTROUT PROPERTY

The Armentrout property is northeast of Green Hill, about 2.2 miles northwest of Edom, and on the southwest side of State Road 780 about 0.6 mile west of the intersection of road 910. In the mineralized exposures near Joes Creek, the sphalerite occurs in a white vein dolomite that cements a rock dolomite breccia. This mineralized area is in approximately the same stratigraphic horizon as that of the Bowers-Campbell and Vetter occurrences. There are three separate areas of exposure, spaced roughly along the strike of the Beekmantown dolomite.

SHOWALTER PROPERTY

The mineralized prospect on the Showalter property is sometimes referred to as the "Snapp Creek lead mine." The occurrence is about 4 miles west of Edom, on the east bank of Snapp Creek, and on the west side of State Road 752 about 0.2 mile north of its intersection with State Road 769. Mineralization, that consists of galena associated with white dolomite and quartz, appears to be in the lower Beekmantown. The same belt of outcrop of Beekmantown contains the Bowers-Campbell, Armentrout, and Showalter sphalerite occurrences in its upper horizons farther to the northeast.

MINNICK PROPERTY

Several small prospect pits on this property are along the west side of a low hill about 0.5 mile northwest of U. S. Highway 11, 2 miles southwest of New Market, and about 2 miles northeast of Concord Church. The mineralized horizon probably is in the upper Beekmantown. The principal sulfide present is sphalerite, but pyrite and chalcopyrite occur.

WISELAND FARM

Sphalerite mineralization occurs on Wiseland farm about 3.3 miles southeast of Melrose and 0.3 mile east of the intersection of State Roads 620 and 722. The horizon of mineralization is in the upper Beekmantown. No known prospecting has been done on this property.

COPPER

Copper has been mined, on a small scale, at a number of places in the Blue Ridge. One abandoned mine is on Hightop, about 7 miles east of Elkton, in Greene County not far from the Rockingham County line. The occurrence of azurite in Rockingham County in prospects near High Knob, southeast of Elkton, was reported by Schrader (1917, p. 313).

CARBONATE ROCKS

The carbonate rocks, limestone and dolomite, have extensive use in industry. Some uses are determined principally by the physical character of the rock and others are dependent chiefly on the chemical composition (Pl. 19B).

Some of the major uses for limestone (crushed and broken stone) are: (Industrial Minerals and Rocks, 1960, pp. 188-189).

concrete and roadstone
fluxing stone
agriculture
riprap
railroad ballast

Miscellaneous uses include:

cement	sugar processing
lime and dead-burned dolomite	calcium carbide works
alkali works	paper mills
filler	refractory
glass manufacture	poultry grit

Rockingham County is well endowed with beds of limestone and dolomite between the South Fork of the Shenandoah River and Little North Mountain. The carbonate rocks are chiefly in the Cambrian and Ordovician formations that have many areas of extensive exposure. Several belts of New Market (Mosheim) limestone, an important "quarry-rock" in the Shenandoah Valley, cross the county in a northeast-southwest direction. The geologic map may be consulted for the locations of this rock. Excellent coverage of the county by a network of good paved highways and all-weather roads makes for easy access to almost all the potentially useful areas of limestone and dolomite. The several railroads in the county, Chesapeake-Western, Southern, and Norfolk and Western, provide favorable means for long-distance transportation.

ACTIVE QUARRIES IN ROCKINGHAM COUNTY

(Statistical data are chiefly from
Virginia Division of Mineral Resources,
Mineral Resources Report 1, 1960)

The Betts quarry, just east of Harrisonburg (Pl. 1, quarry 13), produces limestone for use chiefly as concrete aggregate, roadstone, agstone (agricultural stone), and stone sand. The rock structure is complex locally but observations indicate that most of the rock quarried is from a klippe of Edinburg limestone surrounded by uppermost Beekmantown formation. However, the character of the rock is not typical of either the Edinburg or Beekmantown formation, and in the absence of fossils the identification of the rock is uncertain. In 1959 the quarry was about 2,500 feet long, 500 feet wide and 70 feet deep, and had a production rate of about 900 tons a day.

Three adjacent quarries are operated by the Elkton Lime and Stone Co., about 3 miles northwest of Elkton (Pl. 1, quarry 15), and produce rock for concrete aggregate, roadstone, and other uses. The quarries are in the upper half of the Beekmantown formation that contains considerable limestone locally. The western edge of the westernmost quarry abuts a small fault and the New Market-Lincolnshire appears to be absent. A composite sample of about 78 feet of Beekmantown dolomite from one of the quarries contains 57.28 percent calcium carbonate, 37.01 percent magnesium carbonate, and 3.52 percent silica (Edmundson, 1945, p. 134). The dimensions of the largest quarry in 1958 were: 600 feet long, 200 feet wide, and 75 feet deep. Production of the quarries is approximately 700 tons per day.

About ½ mile west of Harrisonburg the R. Y. Frazier quarry (Pl. 1, quarry 11) produces limestone for concrete aggregate, roadstone, agstone, and stone sand. The quarry is in dark-colored limestone of the Edinburg formation. The quarry, in 1957, was about 500 feet long, 250 feet wide, and 105 feet deep. The production rate is about 600 tons per day.

A quarry, operated by the Jamison Black Marble, Co., just north of Harrisonburg (Pl. 1, quarry 10) produces from the Edinburg formation. The main use of the quarried rock is for terrazzo. No statistics are available on the size or production rate of this quarry.

The C. S. Mundy quarry about 3 miles southwest of Cootes Store (Pl. 1, quarry 3) produces carbonate rock for use as roadstone, agstone, concrete aggregate, and lime. This quarry is along the main trace of the Little North Mountain fault, where the Elbrook dolomite is faulted over dolomites of the Beekmantown formation. The broken and brecciated nature of the rock aids in quarrying and other processing by the operator. In 1957 the quarry was approximately 200 feet long, 250 feet wide, and 70 feet deep. About 800 tons of rock are produced per day.

Analyses of carbonate rocks from various places in Rockingham County are given below (Data from Edmundson, 1945, pp. 76-100).

TABLE 4.—*Chemical Analyses of Carbonate Rocks*

Locality	Formation	CHEMICAL COMPOSITION, PERCENTAGES					
		$CaCO_3$	$MgCO_3$	SiO_2	Fe_2O_3	Al_2O_3	Total
1	New Market (Mosheim)	94.00	2.82	2.44	0.24	0.78	100.28
2	New Market (Mosheim)	96.96	1.21	1.20	0.08	0.40	99.85
3	New Market (Mosheim)	98.35	0.76	0.18	0.08	0.50	99.87
4	Lincolnshire (Lenoir)	96.96	0.89	0.40	0.32	0.88	99.45
5	Lincolnshire (Lenoir)	94.34	1.33	2.52	0.80	0.98	99.97
6	New Market (Mosheim)	98.76	0.74	0.22	0.08	0.58	100.38
7	New Market (Mosheim)	98.17	0.67	0.40	0.08	0.34	99.66
8	Edinburg (Athens)	89.96	3.83	5.20	0.16	0.72	99.87
9	Elbrook	53.36	41.66	4.72	0.40	0.32	100.46
10	Beekmantown	52.56	40.16	7.16	0.52	0.40	100.80

Localities:

1 About 1.5 miles northwest of Timberville.
2 About 3.5 miles northwest of Linville.
3 About 2 miles southwest of Daphna.
4 Southwestern end of Southern Lime and Stone Works' quarry at Linville.
5 About ½ mile southwest of Linville, about 0.2 mile west of Road 753.
6 About 1.5 miles southwest of Linville, near Road 765.
7 Near Cedar Grove Church, about 2 miles east of Harrisonburg.
8 About 2.5 miles northwest of Harrisonburg.
9 About 2.5 miles north of Mt. Clinton.
10 About 2 miles southeast of Mt. Crawford.

MARBLE

Relatively few of the rocks in Rockingham County are classed as metamorphic and there is little or no rock that properly would be called marble. However, from the industrial standpoint there are occurrences of marble in the county. The Jamison Black Marble Co. operates a quarry in the Edinburg formation north of Harrisonburg. The rock is crushed at the quarry chiefly for use as terrazzo.

There are many exposures in the county of "travertine" in old and in present stream beds. Bowles (1960, p. 330) in referring to the onyx marbles, also called Mexican onyx and cave onyx, said: "They are chemical precipitates of calcium carbonate from cold-water calcareous springs. A closely related rock, travertine, is regarded as a product of precipitation from hot springs." According to this definition most of the deposits of calcium carbonate in stream beds and caves of the county would not commercially be classed as travertine. However, both cave onyx and travertine are classed commercially with the marbles.

About 5.5 miles west of the city limit of Harrisonburg and about ¾ mile southwest of Hinton is a small knob in the lower Beekmantown dolomite that is known as Onyx Hill. In one place on the west side of the hill some large blocks of rock are strewn about the ground just below a small opening. Some of the rock in this man-made cave is banded and some is porous; all would be called "travertine" or cave onyx. A superficial examination by the writer indicates that the deposit is small and that there is insufficient good quality onyx to warrant a commercial enterprise. It is not known how long it has been since the opening was made, but there has been no quarrying activity for more than ten years.

BUILDING STONE

The carbonate rocks of the county seem to be suitable for building stone but relatively little use is made of them for this purpose. Most of the buildings of Madison College in Harrisonburg, and some of the city's public buildings, churches, and private dwellings are constructed of native rock.

Limestones of the Edinburg and New Market formations are, perhaps, the most desirable of the local stones for construction purposes, and they are the ones that have been used most. Limestone from the Edinburg formation is commonly dark blue to black when freshly broken, but after several years it weathers to a pleasing light gray or white color. New Market limestone is light tan when fresh but after weathering bears a strong resemblance to the weathered surface of the Edinburg rock. Both fashion and cost are probably important factors in determining the use of the limestones as dimension stones.

CEMENT MATERIALS

Portland cement is a principal ingredient of concrete that is probably the most universally used building material of today. It has been estimated that more tons of concrete are used annually than all other building materials combined (Clausen, 1960, p. 203). Limestone is commonly a chief ingredient of cement and the possibility of utilizing some of the limestones of Rockingham County in cement manufacture was suggested years ago (Bassler, 1909). Certain things, as clay and sand, are not objectionable materials in limestone for cement manufacture as they commonly supply the necessary amounts of alumina, silica, and iron oxide. The principal controlling factor in determining the suitability of limestone for cement manufacture is the magnesium oxide content. Desirable limestone contains less than 3% magnesium oxide and such rocks are uncommon.

The table of analyses of carbonate rocks, Table 4, shows that the New Market limestone meets the specifications for cement manufacture. It appears that several localities could be found in the county suitable for the establishment of a cement plant.

CLAY AND SHALE

Clays may be divided into two general types, sedimentary or transported clays and residual clays. In the Appalachian Mountains province two subtypes of sedimentary clays are noted: surface clays of Recent age, and shales of Paleozoic age (Ries and Somers, 1920). Surface clays are generally found in flat areas bordering streams and commonly are somewhat sandy. These deposits, that are used chiefly for brick and tile manufacture, are not very extensive and may show horizontal and vertical changes from clay to sand or gravel. Consolidated clays, or shales, are usually much more extensive than the surface clays of Recent age, show considerable variation, and commonly have interbedded sandstone beds or limestone layers. Residual clays in the Valley may be derived from weathering of limestone, shale, and sandstone; the most important deposits are related to limestone and to shale. The occurrence of residual clays from limestones has been reported near Elkton, Harrisonburg, and Dayton (Ries and Somers, 1920, pp. 41-42).

Evaluation analyses of nine shale localities are listed below. These analyses were determined by the electro-technical laboratory of the U. S. Bureau of Mines at Norris, Tennessee. (Sample number refers to shale locality on Plate 2). Martinsburg shale Samples No. 1, 2, and 3; Brallier shale, Samples No. 4, 5, and 6; Chemung shale, Samples No. 7 and 8; Millboro shale, Sample No. 9. (Samples No. 2, 5, and 6 collected by R. S. Wood).

ANALYSES OF SHALE SAMPLES

Sample No. 1 (R-377). Martinsburg shale. One-half mile south of Penn Laird, on south bank of Cub Run.

Type: Shale
Color: Gray
pH: 6.9
Unfired strength: Low

Raw Properties: Fair plasticity, smooth working, slightly gritty, requiring 17.0% water for plasticity, no drying defects, 1.0% drying shrinkage.

Fired Properties:

Temp. °F.	Color	Hardness	% Shrinkage	% Absorption	Approx. Sp. Gr.
1800	Lt. brown	Soft, crumbly	2.5	11.0	2.55
2000	Med. brown	Hard	3.5	6.8	2.49
2100	Med. brown	Very hard	3.5	5.9	2.50
2200	Dk. brown	Steel hard	7.5	1.7	2.45
2300	Dk. brown	Steel hard	7.5	1.7	2.46
2400	Nearly black	Steel hard	Expands	0.8	2.00

Potential Use: Brick and tile.

Sample No. 2 (R-1183). Martinsburg shale. About 1.5 miles south of Penn Laird, on east side of State road 674.

Type: Shale
Color: Red-gray
pH: 7.90
Unfired strength: Low

Raw Properties: Not too plastic, short and gritty working, requiring 19% water for plasticity, no drying defects, 3.0% drying shrinkage.

Fired Properties:

Temp. °F.	Color	Hardness	% Shrinkage	% Absorption	Approx. Sp. Gr.
1800	Buff	Crumbly, soft	2.0	15.6	2.75
2000	Lt. red	Fairly hard	4.0	10.0	2.66
2100	Very dk. red	Very hard	8.5	5.9	2.62
2200	Dk. red-brown	Glazed	7.5	3.1	2.41
2300	Very dk. brown	Expands	....	9.8	2.12

Potential Use: Common brick and possibly lightweight aggregate.

Quick Firing Test—15 minutes Retention Time

Temp. °F.	% Absorption	Bulk Sp. Gr.	Lb./ft.^{3}	Remarks
1900	5.7	2.03	126.5	No bloating
2000	4.6	1.62	100.9	No bloating
2100	4.7	1.24	77.3	Good expansion
2200	4.9	0.78	48.6	Overbloated and sticky
2300	6.2	0.80	49.8	Overbloated and very sticky and melting

Firing Characteristics: Bloating range rather short, but sample would probably make acceptable aggregate.

Sample No. 3 (R-379). Martinsburg shale. Two miles south of Broadway on State Route 42.

Type: Shale (high calcium)
Color: Red-gray
pH: 8.8
Unfired strength: Low

Raw Properties: Slightly plastic, short working requiring 21.0% water for plasticity, no drying defects, 4.5% drying shrinkage.

Fired Properties:

Temp. °F.	Color	Hardness	% Shrinkage	% Absorption	Approx. Sp. Gr.
1800	Gray pink	Soft, crumbly	Expands	40.6	2.85
2000	Gray pink	Soft, crumbly	Expands	42.7	2.84
2100	Lt. buff	Soft, crumbly	Expands	40.4	2.78
2200	Orange buff	Soft, crumbly	10.5	19.2	2.72
2300	Dk. buff	Fairly hard	....	....	....

Potential Use: None, very high in calcium, 2300° F. specimen disintegrated in water.

Sample No. 4 (R-397). Brallier shale. North side of road, 1.25 miles west of Brocks Gap.

Type: Shale
Color: Gray-red
pH: 6.20
Unfired strength: Low

Raw Properties: Not plastic, short and gritty working, 19.0% water for plasticity no drying defects, 5.0% drying shrinkage.

Fired Properties:

Temp. °F.	Color	Hardness	% Shrinkage	% Absorption	Approx. Sp. Gr.
1800	Orange buff	Soft, crumbly	2.5	14.0	2.62
2000	Orange buff	Soft, crumbly	3.5	11.4	2.58
2100	Lt. red brown	Very hard	7.0	6.9	2.52
2200	Red-brown	Steel hard	7.5	3.8	2.44
2300	Dk. brown	Steel hard	8.0	2.6	2.37
2400	Dk. brown	Steel hard	8.5	1.8	2.37

Potential Use: Common brick.

Sample No. 5 (R-1184). Brallier shale. North side of U. S. Highway 33 about 1.75 miles southeast of Rawley Springs.

Type: Shale
Color: Red-gray
pH: 6.6
Unfired strength: Low

Raw Properties: Fairly plastic and smooth working, requiring 22% water for plasticity, no drying defects, 1.0% drying shrinkage.

Fired Properties:

Temp. °F.	Color	Hardness	% Shrinkage	% Absorption	Approx. Sp. Gr.
1800	Buff	Crumbly, soft	1.5	15.9	2.47
2000	Reddish buff	Crumbly, soft	4.5	11.9	2.46
2100	Dk. red	Very hard	9.5	3.2	2.41
2200	Very dk. red-brown	Steel hard	10.5	1.4	2.34
2300	Dk. brown	Sl. glazed	10.5	0.6	2.24
2400	Very dk. brown	Expands	5.5	2.0	1.98

Potential Use: Brick and tile and lightweight aggregate.

Quick Firing Test—15 minutes Retention Time

Temp. °F.	% Absorption	Bulk Sp. Gr.	Lb./ft.³	Remarks
1900	4.2	2.06	128.3	No bloating
2000	4.3	1.81	112.8	No bloating
2100	4.6	1.42	88.5	Fair bloating
2200	4.5	1.15	71.6	Good bloating
2300	4.0	0.81	50.5	Overbloated and very sticky.

Firing Characteristics: Very good aggregate material, uniform expansion, long bloating range, and low absorption.

Sample No. 6 (R-1185). Brallier shale. At intersection of State roads 820 and 961, about 2.75 miles north of Bergton.

Type: Shale
Color: Red-gray
pH: 7.00
Unfired strength: Low

Raw Properties: Fairly plastic and smooth working, no drying defects, 5.5% drying shrinkage, requiring 22% water for plasticity.

Fired properties:

Temp. °F.	Color	Hardness	% Shrinkage	% Absorption	Approx. Sp. Gr.
1800	Buff	Crumbly, soft	6.5	16.8	2.68
2000	Lt. red	Hard	7.5	9.9	2.66
2100	Dk. red	Very hard	11.5	3.1	2.56
2200	Dk. red-brown	Steel hard	12.5	1.8	2.51
2300	Dk. brown	Sl. glazed	....	1.6	2.29
2400	Very dk. brown	Expands	....	9.1	2.31

Potential Use: Brick and tile and lightweight aggregate.
Bloating Test: Negative

Sample No. 7 (R-378). Chemung formation. One mile west of Briery Branch on State Route 257.

Type: Shale (very sandy)
Color: Red brown
pH: 5.9
Unfired strength: Low

Raw Properties: Not plastic, short and gritty working, requiring 19.0% water for plasticity, no drying defects, 1.0% drying shrinkage.

Fired Properties:

Temp. °F.	Color	Hardness	% Shirnkage	% Absorption	Approx. Sp. Gr.
1800	Orange buff	Soft, crumbly	2.0	14.8	2.35
2000	Red buff	Soft, crumbly	2.5	11.0	2.34
2100	Red buff	Soft, crumbly	2.5	10.2	2.34
2200	Med. brown	Fairly hard	4.0	7.2	2.34
2300	Med. brown	Fairly hard	4.0	7.1	2.36
2400	Nearly black	Steel hard	5.0	5.4	2.35

Potential Use: None, fired specimen remained soft through 2200° F.

Sample No. 8 (R-396). Chemung formation. North side of road, 1.5 miles east of Bergton.

Type: Shale (very sandy)
Color: Gray red
pH: 7.70
Unfired strength: Low

Raw Properties: Not plastic, short and sandy working requiring 19.0% water for plasticity, no drying defects, 4.0% drying shrinkage.

Fired Properties:

Temp. °F.	Color	Hardness	% Shrinkage	% Absorption	Approx. Sp. Gr.
1800	Orange buff	Soft, crumbly	2.5	12.1	2.58
2000	Orange buff	Soft, crumbly	3.5	9.5	2.55
2100	Red brown	Fairly hard	5.0	5.8	2.51
2200	Brown	Steel hard	6.5	3.0	2.43
2300	Dk. brown	Steel hard	6.5	3.6	2.35
2400	Dk. brown	Steel hard	6.5	2.7	2.35

Potential Use: Very common brick, color range poor.

Sample No. 9 (R-398). Millboro shale. East side of State Route 259, 3.75 miles south of West Virginia line.

Type: Shale
Color: Gray-red
pH: 4.3
Unfired strength: Low

Raw Properties: Fairly plastic, short working, requiring 19.0% water for plasticity, no drying defects, 5.0% drying shrinkage.

Fired Properties:

Temp. °F.	Color	Hardness	% Shrinkage	% Absorption	Approx. Sp. Gr.
1800	Lt. buff	Soft, crumbly	2.5	17.0	2.61
2000	Orange buff	Soft, crumbly	4.5	12.9	2.58
2100	Lt. red	Very hard	7.5	6.8	2.50
2200	Mottled brown	Steel hard	8.0	2.5	2.27
2300	Mottled gray brown	Steel hard	Expands	2.5	1.96
2400	Mottled gray brown	Steel hard	Expands	Inconclusive	2.02

Potential Use: Common brick (decorative?)

Results of tests made on *Miniature Brick,* fired to 1900° F.

Sample No.	Hardness	% Shrinkage	% Absorption	Approx. Sp. Gr.
1	Steel hard	2.3	5.6	2.70
4	Hard	2.9	7.2	2.71
9	Steel hard	3.7	7.8	2.69

SILICA SAND

There are many possible sources of silica sand in the county as several of the formations that are used for sand sources in other counties of the State have extensive areas of exposure in Rockingham County. Much of the silica sand used commercially in Virginia is supplied to the foundry industry, but little of this is produced within the State. Some of the sand obtained from local sources is used in glass manufacture and some in plaster and concrete. The most important deposits of silica sand in western Virginia are: Erwin quartzite, Clinch, Keefer, and Massanutten sandstones, Oriskany sandstone, and Pocono sandstone (Lowry, 1954, p. 9). All of these formations are present in Rockingham County.

Erwin quartzite occurs on the western slopes of the Blue Ridge and some of the foot-hills are capped by this formation. In many places along the lower slopes are sandy areas that result, at least partly, from disintegration of talus blocks. The qualities of this sand are unknown but in some localities it may be suitable for commercial uses. Sand deposits along the base of Massanutten Mountain probably result from disintegration of talus blocks of Massanutten sandstone. The Clinch and Ridgeley (Oriskany) sandstones crop out in Little North Mountain and farther west in the Adams Run anticline. In the southwestern part of the county is an area of Pocono sandstone that has disintegrated in places to form deposits of loose sand. The possible economic uses of the sand in these areas have not been determined.

SAND AND GRAVEL

Deposits of sand and gravel occur along and near many streams in the county. Production is limited to local contruction uses and there are no specific sand and gravel companies in operation.

COAL

There is no commercial coal production but the occurrence of coal in the county has been known for a long time. The coal beds in the North River coal field crop out on the northwest slope of Narrow Back Mountain from Stokesville in Augusta County to Rawley Springs, Rockingham County (Howell, *in* Campbell and others, 1925, p. 283). This coal field was explored as early as 1834 (Rogers, *in* Taylor, 1855) and the structure was correctly interpreted by Darton (1894, 1896b). The coal is of the semi-anthracite variety (Darton, 1894; Watson, 1907, p. 348).

There are three coal localities in the Rockingham County portion of the North River field: one near Rawley Springs, another near Briery Branch Gap, and the third near the Augusta County line on Wolf Run creek about 2 miles south of Briery Branch. At Briery Branch Gap a drift was driven about 30 feet in a coal horizon and a section in this drift was given by Howell (p. 285) as follows:

	Ft.	*Inches*
Shale, carbonaceous, containing a little coal		3
Shale, hard, blue-gray		1
Shale, carbonaceous		6
Shale, sandy	1	7
Coal, with some shale		4
Shale		2
Coal, with some shale		3
Shale, carbonaceous		5
Coal, impure		3
Shale, black, almost bone		4
Coal		8
Shale, with stringers of coal		6
Coal and shale		4
Thickness of bed	5	8
Thickness of coal (?)	1	10

At the Wolf Creek locality coal is reported to have been dug at about the time of the Civil War and used at a small forge near Briery Branch Gap. Little coal was taken out of the ground and the workings now are caved and covered with vegetation.

Analyses of coal from the North River field (after Watson, 1907, p. 348.)

	Sample 1	*Sample 2*	*Sample 3*
Percent Carbon	89.47	86.35	87.65
Percent Volatile Matter	6.00	7.27	7.58
Percent Water	0.40	0.80	0.80
Percent Ash	4.13	5.58	3.97

Samples 1 and 2 are from an opening on Briery Branch about 100 feet above the base of Narrow (Back) Mountain. Sample 3 is from near Briery Branch at the foot of Narrow (Back) Mountain from a drift 5 or 6 feet in a 4 foot bed.

OIL AND GAS

It is unlikely that significant amounts of oil or gas will be found east of the Little North Mountain fault because of the considerable deformation of the rocks. West of this fault, in the northwestern part of the county, wells have been drilled for and have encountered natural gas.

There was considerable exploration for natural gas during the 1930's and at least four wells were drilled. A well, on the property of C. L. Souder, was completed in 1941 with a total depth of 2,986 feet and had a reported flow of gas of 60,000 to 100,000 cubic feet per day from the top of the Oriskany (Ridgeley) sandstone. In 1951 it was deepened to 2,994 feet, completed as a gas well with initial potential of 1,043,000 cubic feet per day, and shut in. Subsequently, four gas wells and seven dry holes have been drilled in the Bergton area (Le Van, 1959, p. 6). Snee and Eberly of Uniontown, Pennsylvania, completed a gas well in 1952 on the property of S. L. Moyer, with a total depth of 3,077 feet and an initial potential of 9,700,000 cubic feet per day. The United Fuel Gas Company completed a gas well with a potential of 286,000 cubic feet per day in 1952, and two wells with initial potentials of 94,000 and 1,078,000 cubic feet per day in 1956. Information concerning well records is available at the office of the Division of Mineral Resources.

This field is on the southeast flank of the Bergton-Crab Run anticline and gas occurs in the Oriskany (Ridgeley) sandstone at depths of approximately 2,600 feet to 4,000 feet. The Bergton gas field is only a few miles from a pipeline of Columbia Gas System, Inc., but there is no gathering system and all the wells are shut in. Apparently additional exploration is required to determine the future of this field.

OCHER

The term ocher is applied to earthy forms of hematite and limonite; it usually contains impurities of other metallic oxides and of clayey matter. Natural ochers have a color range through various shades of red, brown, and yellow. In the Blue Ridge area ocher is found associated with ores of iron and manganese in the residuum of Cambrian formations. One locality from which ocher formerly was produced is about half a mile east of the settlement of Furnace. The deposit was opened about 1880 and 112 tons were reported to have been mined in that year (King, 1950, p. 77). It was never a big operation and the workings long have been abandoned. Brown ocher was mined along the western base of Massanutten Mountain near Keezletown (Watson, 1907, p. 229). The ocher occurs in or near the upper Beekmantown dolomite and the lower Martinsburg shale.

FLUORITE

Fluorite occurs at a number of places in the Ordovician rocks in the county but commercial quantities are not known. Crystals of fluorite have been found associated with the faulting in the Betts quarry east of Harrisonburg, and in Cambrian or Ordovician age rocks near the Burketown klippe, associated with the Pulaski-Staunton fault. Purple fluorite has been noted at several zinc localities (Herbert and Young, 1956, p. 12).

QUARRIES AND MINES ON PLATE 1.

1.—Abandoned, Elbrook dolomite
2.—Abandoned, Elbrook dolomite
3.—C. S. Munday, Elbrook and Beekmantown dolomites
4.—Abandoned, Conococheague limestone
5.—Tri-State Zinc, Inc., Bowers-Campbell mine, sphalerite
6.—Abandoned, Edinburg limestone
7.—Abandoned, Southern Lime and Stone Works, New Market limestone
8.—Abandoned, New Market limestone
9.—Abandoned, New Market limestone
10.—Jamison Black Marble, Edinburg limestone
11.—R. Y. Frazier, Edinburg limestone
12.—Abandoned, Edinburg limestone
13.—F. K. Betts, Edinburg limestone
14.—Abandoned, Beekmantown dolomite
15.—Elkton Lime and Stone Works, Beekmantown formation
16.—Abandoned, Beekmantown formation
17.—Abandoned, Fox Mountain mine, iron ore
18.—Abandoned, U. S. Manganese Corp., manganese ore
19.—Abandoned, Kendall and Flick, manganese ore
20.—Abandoned quarry, Erwin quartzite
21.—Abandoned, Seller mine, manganese ore
22.—Abandoned, manganese ore?
23.—Gravel pit
24.—Abandoned, Big Run mine, manganese and iron ores
25.—Abandoned, Big Run mine, manganese and iron ores
26.—Abandoned, Shaver mine, manganese and iron ores
27.—Gravel pit
28.—Gravel pit
29.—Gravel pit
30.—Abandoned, stone quarry
31.—Abandoned, Beekmantown dolomite
32.—Abandoned, onyx and travertine

WATER RESOURCES

Water is an essential natural resource and for many years there has been an increase in water consumption. Use of water commonly involves only a temporary "borrowing" and in many cases the water soon is returned to nature and in a relatively short time is ready to be used again. In the "hydrologic cycle" the oceans are considered to be the great natural repositories of water. Evaporation of ocean water forms clouds in the atomsphere; some clouds are blown over land areas where precipitation occurs. Some of it collects to form surface water or streams, part of it soaks into the ground to become sub-surface water, and some serves various other uses, but almost all of it eventually finds its way back to the oceans. Water, then, is a replenishable natural resource but use of it should be regulated so that consumption does not exceed additions to the source of supply.

SURFACE WATER

The major rivers and streams of Rockingham County are: South Fork of Shenandoah River, North Fork of Shenandoah River, North River, Dry River, and Briery Branch. Streams of fair size include Muddy Creek, Linville Creek, and Smith Creek. All these streams are of the permanent type but North River and Dry River may have only subsurface flow in gravel deposits along part of their courses during dry seasons of the year.

The headwaters of Smith Creek come largely from drainage off the west side of the Massanutten ridges, northeast of Lairds Knob. The stream flows across a number of formations and a major fault, the Pulaski-Staunton fault, and joins the North Fork of Shenandoah River southeast of Mt. Jackson, Shenandoah County. Linville Creek rises northwest of Harrisonburg, flows mainly over Martinsburg shale that occupies the center of a syncline, and empties into the North Fork of Shenandoah River at Broadway. The main headwaters of Muddy Creek are on the east side of Little North Mountain, west of Singers Glen, but some of its tributaries begin west of Little North Mountain. Muddy Creek, which is parallel to and just east of a belt of Chepultepec limestone for much of its length, joins Dry River near Rushville.

BRIERY BRANCH

Briery Branch originates largely from streams flowing down the southeast slopes of Shenandoah Mountain. The stream flows through a water gap in Narrow Back Mountain, across Little North Mountain fault, and empties into North River near Spring Creek. At times the stream bed is dry southeast of Briery Branch Gap where the valley is as much as three-fourths of a mile wide and filled with unconsolidated deposits.

DRY RIVER

Dry River begins in a network of small streams on the east slopes of Shenandoah Mountain, flows through a water gap at Rawley Springs, across Little North Mountain fault, and joins with North River at Bridgewater. The bed of the stream is filled with cobbles and boulders and commonly there is little or no surface flow. Large boulders several miles southeast of Rawley Springs attest to the considerable transporting power of the stream during times of high-water volume.

NORTH RIVER

North River flows into Rockingham County from Augusta County, east to Bridgewater, and southeast to near Grottoes where it unites with Middle River. West of Bridgewater the channel commonly is filled with coarse materials and in places there is no surface flow (Pl. 16B). The course of the river has been deflected abruptly by masses of chert in the Beekmantown dolomite at Round Hill and about 1 mile northwest of Rockland Mill Church.

NORTH FORK OF SHENANDOAH RIVER

A network of streams on the east slopes of Shenandoah Mountain gives rise to North Fork of Shenandoah River that flows south from Bergton to Fulks Run, southeast through Brocks Gap to Broadway, and northeast into Shenandoah County. Structural control of the stream is evident along the west side of Church Mountain, an anticline that the stream parallels for 6 miles, and at Brocks Gap where the stream is deflected abruptly by vertical sandstone beds.

SOUTH FORK OF SHENANDOAH RIVER

The largest river in the county begins at Port Republic where the combined flow of North River and Middle River joins South River to form the South Fork of Shenandoah River. The river, which has a flood-plain a mile wide, flows to the northeast parallel to the strike of the underlying Cambrian and Ordovician dolomites and limestones. There are exposures of bedrock in the bed of the river at the old Harrisonburg power plant, at Elkton, and at other places.

TABLE 5.—*Stream Gradients*

Stream	Bedrock	Average Gradient feet per mile
1	dolomite and limestone	8
2	dolomite, limestone, shale	13
2	shale and sandstone	25
3	dolomite, limestone, shale	7
4	dolomite and limestone	43
4	sandstone and shale	61
5	dolomite and limestone	45
5	sandstone and shale	138

Stream 1.—South Fork of Shenandoah River
Stream 2.—North Fork of Shenandoah River
Stream 3.—North River
Stream 4.—Dry River
Stream 5.—Briery Branch

TABLE 6.—*Discharge of Streams, October, 1956—September, 1957 (from U. S. G. S. Water-Supply Paper 1502)*

Location	Discharge in Cubic Feet Per Second				Runoff in inches
	Maximum	Minimum	Mean	Per Square Mile	
1	4,500	38	303	0.80	10.96
2	3,090	65	255	0.70	9.61
3	10,100	168	810	0.75	10.22
4	4,100	0.2	138	0.64	8.70

Location 1.—North River in vicinity of Mt. Crawford, drainage area 375 square miles.
Location 2.—Middle River near Grottoes, drainage area 360 square miles.
Location 3.—South Fork Shenandoah River near Lynnwood, drainage area 1,076 square miles.
Location 4.—North Fork Shenandoah River at Cootes Store, drainage area 215 square miles.

Definition of terms in Table 6:

Cubic foot per second—rate of discharge of a stream whose channel is 1 square foot in cross-sectional area and whose average velocity is 1 foot per second.

Cubic feet per square mile—average number of cubic feet of water flowing per second from each square mile of area drained, assuming that the runoff is distributed uniformly in time and area.

Runoff in inches—depth to which an area would be covered if all the water draining from it in a given period were uniformly distributed on its surface.

Drainage area—drainage area of a stream at a specified location is that area, measured in a horizontal plane, which is so enclosed by a topographic divide that direct surface runoff from precipitation normally would drain by gravity into the river above the specified point.

Below are selected chemical analyses of surface waters collected at stream-gaging stations. (Source: *Chemical character of Surface Waters of Virginia*, 1960, Va. Division of Water Resources Bulletin 23). Dissolved constitutents are expressed in parts per million.

TABLE 7.—*Chemical Analyses of Surface Waters*

Location	1		2		3		4	
Discharge, cfs	62	291	114	215	29	239	887	768
Silica (SiO_2)	6.6	4.2	5.8	2.6	5.0	4.3	6.7	3.6
Iron (Fe)	0.0	0.04	0.16	0.05	0.0	0.0	0.01	0.08
Calcium (Ca)	19	19	25	33	11	7.5	24	22
Magnesium (Mg)	23	12	28	30	0.0	11	8.3	18
Sodium (Na)	3.7	3.0	6.1	4.6	4.4	0.8	8.1	6.6
Potassium (K)	......	9.5	......	2.7	2.0	2.5	1.7	2.3
Bicarbonate (HCO_3)	143	71	171	120	36	23	97	101
Sulfate (SO_4)	7.6	9.4	12	12	12	25	15	13
Chloride (Cl)	3.7	2.5	6.2	0.3	3.2	3.0	4.5	1.6
Fluoride (F)	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0
Nitrate (NO_3)	2.8	3.1	3.6	2.9	1.0	5.2	1.4	3.7
Dissolved solids, in residue on evaporation at 180°C.	160	117	235	176	96	73	134	225
Hardness as Ca CO_3								
Total	144	96	178	157	35	65	94	131
Non-carbonate	72	61	92	97	17	54	46	81
pH	7.8	7.3	8.0	7.8	7.4	6.8	7.6	7.5
Temperature (degrees F.)	74	49	78	39	68	33	64	38
Date	8-13-59	1-12-60	8-13-59	12-1-59	6-17-59	12-25-60	5-5-59	1-13-60

Location 1—North River near Mt. Crawford, drainage area 375 square miles.
Location 2—Middle River near Grottoes, drainage area, 360 square miles.
Location 3—North Fork Shenandoah River at Cootes Store, drainage area 215 square miles.
Location 4—South Fork Shenandoah River near Lynnwood, drainage area, 1,076 square miles.

GROUND WATER

GENERAL STATEMENT

In a general way the permeable materials below the surface are divided into the zone of aeration and the zone of saturation. In the zone of aeration, which extends from the surface down to the water-table, the open-spaces are not permanently filled with water. Below the water-table, which is the upper surface of the saturated zone, the open-spaces are permanently occupied by water. The term "ground-water" refers to water in the saturated zone that extends downward to the depth at which there are no openings large enough to allow free movement of water. The water-table is the level of standing water in a well and generally is coextensive with the level of permanent streams and lakes. Clearly, the level of the water-table is subject to fluctuations. Because of the restrictive influence of small openings in rocks, the configuration of the water-table is roughly the same as the shape of the surface of the ground above. The water-table is higher in elevation below a hill than under an adjacent valley, but is at a greater depth below the surface of the ground on a hill than below the floor of the valley, Ground water originates chiefly by downward seepage of surface water which may come from rain, melted snow and ice, and from some streams and lakes. This origin is demonstrated by the rise in the water-table after precipitation, and the lowering after a period of drought.

Different types of rocks have different water-bearing properties although variations exist and exceptions are common. Following are examples of water-bearing properties commonly associated with certain rock types. Well-sorted coarse gravel is the most productive unconsolidated water-bearing material and the next is coarse sand. The water-bearing properties of consolidated rocks are chiefly dependent upon their physical character and their history. The most common rock types at and near the surface of the ground are shale, sandstone, and limestone (including dolomite). Shales are composed of such fine-grained material that they transmit water only along bedding planes or through cracks or similar openings. Sandstones are permeable (allow free movement of water) if the pore-spaces are partly filled, and are impermeable (will not allow free movement of water) if the pore-spaces are completely filled. Limestones commonly have solution channels through which water may flow. Cracks in any type of rock will transmit water.

ROCKINGHAM COUNTY

Rockingham County is not known to have acute ground-water problems. No doubt this is partly because of the humid climate and partly because of adjustment of water needs to the most readily available water supplies. The surface rocks of the county are chiefly shales, sandstones, and limestones. Geological structure, which has a bearing on the availability of ground water, is complex and variable throughout the area. In some places the structure creates favorable conditions for the accumulation of ground water in underground reservoirs, and in others conditions are unfavorable. Predictions as to the occurrence of ground water are difficult to make because they are dependent upon a variety of complicated and inter-acting factors such as the source of supply of water and the chemical, physical, and structural characteristics of the rocks in the area. Since the occurrence of ground water is related to rock type, topography, and geologic structure, the county may conveniently be divided into three major hydrologic areas. The first area includes the South Fork of Shenandoah River and the west slopes of the Blue Ridge, the second, the east slopes of Shenandoah Mountain down to Little North Mountain and Little North Mountain fault, and the third is the central part of the county, which lies between the first two areas. Some records and information regarding ground-water conditions in the county are published in Virginia Geological Survey Bulletin 45 (Cady 1936).

SOUTH FORK OF SHENANDOAH RIVER AND WEST SLOPES OF BLUE RIDGE

Bedrock in the river valley and along the lower mountain slopes is chiefly dolomite and limestone, shale, and sandstone. The formations or beds of rock trend roughly parallel to the trend of the mountains, so different kinds of rock are encountered by going in a northwest or southeast direction. Sandstones generally are hard and dense and do not allow movement of water through them except where they are cracked or where weathering has loosened the grains. The shales are mostly impervious to water except in broken zones. Limestone (including dolomite) is mainly younger than the other types and commonly lies interbedded with or on top and to the west of the sandstones and shales. Dolomite formations occur in the valley at the bottom of the mountains and underlie the river itself. These dolomites have been deeply weathered in many areas and commonly are covered by residuum or water deposited sediment or by both. Solution channels in the dolomite, which are not plugged by mud or clay materials, are potentially good aquifers.

In the vicinity of Elkton, there are many folds and faults which distort and break the rocks. The dips of the Cambrian formations along both sides of the river are commonly steep, and in many cases the rocks are overturned and dip to the southeast. To the southwest, near Grottoes, the formations are largely covered but available exposures indicate that the rocks dip to the west, commonly less than 45 degrees. This area appears to have no large faults.

Throughout the course of the South Fork of the Shenandoah River there are gravel deposits on the eastern side which in places are tens of feet thick. The lower parts of the valleys of streams that drain the west side of the Blue Ridge are filled with coarse gravels and boulders and the surface of the stream beds in such areas are commonly dry. Much of the water in streams draining the west slopes of the Blue Ridge sinks into gravels on the east side of the river. This water eventually reaches the river by subsurface drainage or by surface flow from springs. Also, some solution channels in the limestones and dolomites probably carry large amounts of water to the river. Certain areas east of the river seem to contain sites where plentiful supplies of ground water could be obtained but there is no way to be certain except by drilling. Water wells with large yields have been drilled south of Elkton, at the plant of Merck and Co., and at Grottoes. Some of the results are noted below.

Merck and Co., has nine wells at its chemical plant which yield from about 300 gallons per minute to more than 1000 gallons per minute. The depth of the wells varies from about 70 feet to about 330 feet. The depth to the chief water-bearing zone shows considerable variation; in one well it is between 50 and 75 feet and in another between 302 and 307 feet. One shallow well was pumped for nine hours at 1175 gallons per minute and had a drawdown of only 5 feet. A well at the town of Grottoes was drilled to a depth of 303 feet where the main supply of water was encountered. A drawdown of only 5 feet resulted after the well was pumped for 24 hours at 200 gallons per minute.

The area along and near the east bank of South Fork of Shenandoah River is recommended as having a probable good ground-water potential.

EAST SLOPES OF SHENANDOAH MOUNTAIN TO LITTLE NORTH MOUNTAIN

This area is underlain chiefly by Devonian sandstones and shales but rocks of other ages and other types occur. Especially notable is the occurrence of Mississippian sandstone (Pocono) in the southern part of this area. The shales are commonly impermeable except where fractured but little is known of the permeability of many of the sandstones. From the appearance of most of the sandstones in outcrops they probably are too impermeable to be good aquifers in general. The Ridgeley sandstone is sufficiently permeable to be a gas horizon at considerable depth but little is known of its properties as an aquifer close to the surface. Because of the high solubility of the calcareous cement of the Ridgeley this formation probably is potentially a good aquifer; however, it seems to lack a good catchment area locally. The Pocono sandstone is firmly cemented and is probably largely impermeable.

Structurally, this area as a whole is relatively uncomplicated. There are many small folds and faults which serve as openings for underground movement of water and small supplies commonly can be obtained. The Ridgeley sandstone and the underlying limestones probably would transmit water if the structural and topographic relations were favorable. West of Little North Mountain these formations are exposed in the

Adams Run anticline, but there is a small catchment area and dips are relatively steep so the formations are below normal water-well depth a short distance from their outcrop.

The Pocono sandstone occurs mainly as an overturned syncline with gentle southeast dips on the west flank and vertical to steep southeast dips on the east limb. The west flank of the fold could carry water eastward from the mountains and the steep southeast limb would prevent its escape. Thus, there is here a potential artesian system, that is, a system so constructed that in places the water is under hydrostatic pressure and will rise in a well above the level at which it is encountered. Another possibility is that water occurs in cracks formed by fracturing during tight folding. A network of such fractures could yield artesian water if a crack was intercepted at some depth below the level of the water.

In Augusta County, several miles south of Rockingham County, where the structure and stratigraphy are the same, an artesian well is said to have been drilled a short distance west of the steep upturned beds of the east flank of the syncline (W. R. Brown, oral communication). Somewhat similar structural conditions are presented by Little North Mountain, and the area west of the trend of the mountain may have some areas favorable for ground water accumulation. Several test wells, located at selected sites, are necessary to indicate the groundwater potential of these structures, but undoubtedly some water could be obtained.

The beds of most of the large streams are filled with coarse gravels and boulders and the streams flow beneath the surface in many places. The Harrisonburg municipal water supply is obtained principally from water stored in the gravels upstream from a dam that extends across the valley of Dry River. Dams across other stream valleys could be constructed for water storage where similar conditions exist.

Few water well completion reports are available for the area west of Little North Mountain but there is some information concerning the area near Fulks Run. From this data it appears that the shales are the most likely water producers. Several wells drilled into shale at depths between 40 and 65 feet have yields of between 16 and 25 gallons per minute.

CENTRAL PART OF COUNTY

The surface and near surface rocks in the central part of the county are mostly Cambrian and Ordovician limestones and shales. Shale areas commonly yield small quantities of water for domestic use from fracture zones and along bedding planes. Sulphur and iron commonly are present but usually not in sufficient quantities to prevent use of the untreated water. An abundance of solution features indicates that the limestone and dolomite areas have networks of cavities in many areas. A well in limestone probably will be successful only if a water-filled cavity is encountered. The water from limestone is likely to be hard, and since the water usually flows in channels there is danger of pollution from nearby areas. Relatively thin sandstone horizons in the Conococheague limestone formation may be considered as potential water bearers where the cement has been dissolved.

Structural lows, synclines, are likely structures to collect water because of downward movement of water under the influence of the force of gravity. Favorable places to obtain water might be the synclinal area along and southwest of Massanutten Mountain, the syncline extending southwest from Harrisonburg, and the syncline extending southwest from near Timberville. Some of the water that falls between the Massanutten Ranges soaks into the ground and some forms surface streams. It seems likely that the shale area between the sandstone ridges may be saturated with much recoverable water.

Springs are common along fault zones attesting to the existence of open spaces along and adjacent to many faults. The county is crossed in a northeast-southwest direction by two major thrust faults, the Pulaski-Staunton fault and the Little North Mountain fault. Some small springs occur near these faults but there are no large springs that clearly are related to them. Even so, a well drilled to intersect a fault zone, especially near the Little North Mountain fault, might encounter good supplies of water.

An area of possible potential water production exists near the exits of Dry River and Briery Branch from the mountains on the west. This area has a considerable cover by coarse, unconsolidated material of an unknown depth. When the streams from the mountains to the west enter this loose material much water goes underground into the pore-spaces. There has not been enough drilling here to evaluate the ground water potential, and it is suggested that this area may have ground water possibilites. Drilling sites should be located only after intensive study by qualified personnel, and not chosen indiscriminately.

Some idea of ground water conditions in the vicinity of Harrisonburg may be obtained from well logs. Information as to the exact location of the wells and the water-bearing horizons is not always available. Following is a list of depths and yields of some wells in and near Harrisonburg:

TABLE 8.—*Water well depths and yields.*

Depth in feet	Yield—gallons per minute	Rock Type
60	25	limestone
152	60	....
195	10	shaly limestone
226	250	....
235	6	limestone
280	3	shaly limestone
302	24	....
305	15	shale
600	100	....
*1322	60	....
*1926	90	....

*data from Cady, 1936, p. 38.

MUNICIPAL WATER-SUPPLIES

A brief discussion of the sources of water for some of the towns may give some idea of ground water supplies in various parts of the county. The information was obtained largely from personnel of the water departments of the various towns.

HARRISONBURG

The main supply of water for Harrisonburg comes from the valley of Dry River about 1¼ miles north-northwest of Rawley Springs. Water is stored in the river gravel upstream from a dam across the valley and conducted to town through pipes. The necessary transporting force is furnished by gravity. Harrisonburg uses about 1.8 million gallons of water per day and all the water comes from this source except for about 30 days a year, when an additional source is needed. The extra supply is obtained from Silver Lake near Dayton, 3 or 4 miles southwest of Harrisonburg. The water from Dry River is soft and needs little treatment before it is used. The only additives are chlorine and sodium fluoride, 1 part per million of each, and a rust inhibitor.

An analysis of water from the plant at Riven Rock by the Calgon Co. in 1958 is as follows:

Hydroxide...........	(OH)	0	ppm
Carbonate...........	(CO_3)	0	
Bicarbonate	(HCO_3)	8	
Chloride.............	(Cl)	2	
Iron.................	(Fe)	0.05	
Calcium..............	(Ca)	2	
Magnesium...........	(Mg)	0.5	
Hardness............	(as $CaCO_3$)	6	
Metaphosphate.......	(as $NaPO_3$)	1.8	
Orthophosphate......	(as $NaPO_3$)	0.2	
pH value as received..................		6.4	
Sample appearance....................		clear	

ELKTON

Many residents of Elkton get their water from individual shallow wells. The town water supply comes chiefly from a spring about 0.5 mile southeast of town. Water is pumped from the spring to a hill-side reservoir, where chlorine is added, and flows to Elkton by gravity. This system furnishes about 500 thousand gallons of water to the municipality each day.

BRIDGEWATER

The town water supply comes from Warm Spring which issues from Edinburg limestone about 0.5 mile south of Bridgewater. Between 120 and 150 thousand gallons of water are pumped every 24 hours. Both chlorine and a water softener are added to the water. A survey of the local water supply conditions was made recently by a consulting engineering firm which recommended that additional supplies, if needed, could be obtained from nearby North River.

DAYTON

The water source for Dayton is adjacent Silver Lake, which also serves as a reserve supply for Harrisonburg. Silver Lake is fed by a spring, in the Beekmantown dolomite, which has a rate of flow of approximately 5 million gallons per day.

BROADWAY

Broadway's water supply comes partly from the North Fork of Shenandoah River and partly from wells. One of the wells is 120 feet deep and yields about 100 gallons per minute.

TIMBERVILLE

A spring with a flow of about 200 thousand gallons per day supplies much of the water for Timberville. A supplementary source is a well that has a depth of 146 feet and a yield of about 40 gallons per minute. A recently drilled well that has a depth of 270 feet and a yield of about 50 gallons per minute is to be added to the municipal system.

GROTTOES

The town of Grottoes gets much of its water from a well that is 303 feet deep and will yield 200 gallons per minute. After pumping at the rate of 200 gallons per minute for 24 hours the drawdown was only 5 feet.

TABLE 9—*Chemical Analyses of Municipal Water-Supplies*
(data from: *Public Water-Supplies in Virginia*, 1939)
Results, except pH, are expressed in parts per million.

	Bridge-water	Broad-way	Dayton	Elkton	Timber-ville
Date collected	4-15-38	4-13-38	4-15-38	4-15-38	7-1-38
pH	7.1	7.0	7.4	7.6	....
Dissolved Solids	403.0	67.0	283.0	139.0	283.0
Volatile Matter	209.0	22.0	145.0	64.0	106.0
Mineral Residue	194.0	45.0	138.0	75.0	177.0
M. O. Alkinity ($CaCO_3$)	265.0	22.0	230.0	108.0	260.0
Normal Carbonates ($CaCO_3$)	0	0	0	0	0
Bicarbonates (HCO_3)	323.3	26.8	280.1	131.8	317.2
Free Carbon Dioxide (CO_2)	27.0	3.0	15.0	2.0	....
Sulphates (SO_4)	11.0	21.1	8.5	4.1	9.9
Chlorides (Cl)	3.4	1.4	1.9	1.9	2.0
$Fe_2O_3 + Al_2O_3$	3.8	2.8	4.0	2.2	3.6
Colorimetric Iron (Fe)	0	0.35	0.15	trace	trace
Calcium (Ca)	79.6	14.8	58.4	24.0	83.5
Magnesium (Mg)	18.9	1.7	24.9	13.4	17.4
Cal. Hardness as ($CaCO_3$)	276.5	43.9	248.3	115.0	280.1
Soap Hardness	278	30.0	300.0	114.0	300.0

SPRINGS

Springs are the result of a natural flow of ground water to the surface. They may issue from any type of rock and are controlled by a variety of conditions such as rock type, rock structure, and source of supply. In general, the largest springs in Rockingham County issue from cavernous limestone or dolomite.

SILVER SPRING

Silver Spring, just north of Dayton, is used as the main water supply for the town and as an auxiliary supply for Harrisonburg. The spring is said to have a single, large opening, and the water issues from the upper part of the Beekmantown formation. Underground flow is undoubtedly through solution channels in limestone. The rate of flow is said to be about 5 million gallons per day, and no drop in water level of the spring-fed lake has been noticed at any time of the year.

SPRING CREEK

Spring Creek, or Patterson Spring, is the name for a spring about 1 mile northwest of Spring Creek Post Office. The water issues from the Conococheague formation and fills a large natural basin, more than 50 feet in diameter. The spring never goes dry but during one extreme drought the overflow from the basin ceased. Flow is through cavernous limestone and at the point of exit the water is so deep that the bottom cannot be seen even through clear water. Local residents claim that a weight tied to the end of a rope 90 feet long did not reach bottom when lowered into the spring. The rate of flow according to Collins, and others, (1930) is about 5,760,000 gallons per day, but a visual estimate by the writer in September, 1959, suggested a flow of no more than one-tenth this amount. Residents say that the flow shows marked responses to changes in amount of rainfall.

MASSANETTA SPRINGS

There are at least three separate springs at Massanetta Springs, about 4 miles southeast of Harrisonburg. These springs issue from Beekmantown dolomite about 0.5 mile west of the main trace of the Pulaski-Staunton fault. The flow of the main spring was about 576,000 gallons per day, but the rate of flow is subject to variation (Collins, and others, 1930). Following is an analysis of the water taken from a plaque at the spring-house. Units are not stated, with one exception, but are probably in parts per million. The date given is 7-29-55 and water temperature is 55.9°F.

Nitrogen gas	86.67
Carbonic anhydrite gas	2.64
Oxygen gas	8.44
Marsh gas	2.25
Sodium carbonate	1.128
Magnesium carbonate	6.949
Iron (ferrous) carbonate	0.375
Manganese carbonate	0.057
Calcium carbonate (in grains per gallon)	14.778
Lithium	trace
Ammonium chloride	0.012
Potassium chloride	0.163
Potassium sulphate	0.113
Calcium sulphate	0.414
Alumina	0.169
Arsenious oxide	trace
Phosphoric acid	trace
Silica	1.134
Organic matter	0.480
Acid carbonates	10.576

RAWLEY SPRINGS

About 11 miles northwest of Harrisonburg is the former resort of Rawley Springs. The three small springs which issue from a syncline in Pocono sandstone, are called "chalybeate springs" from the peculiar taste due mainly to the presence of iron in the water. During the latter part of the 1800's the resort operators intimated that the water might have medicinal effects. An analysis by Mallet (1874) of water from the main spring is as follows:

Flow	1.58 Imperial gals. per minute
Temperature (water)	51.8° F.
Temperature (air)	approximately 65° F.
Pentoxide of Iron	1.3214 grains per Imperial gallon
Pentoxide of Manganese	0.0122
Alumina	0.0514
Magnesia	0.3874
Lime	0.3536
Lithia	trace
Soda	0.3068
Potash	0.0721
Ammonia	trace
Sulphuric Acid	0.5208
Chlorine	0.0315
Silicia Acid	0.8163
Carbolic Acid (combined)	1.5624
Organic Matter (including Humoid Acid)	0.3531

Gases dissolved:

Carbonic Acid	7.42 cubic inches per Imperial gallon
Oxygen	2.07
Nitrogen	4.18

LACEY SPRING

Lacey Spring, about 9 miles northeast of Harrisonburg, issues from a syncline in the Edinburg formation. The spring has a flow of 5,760,000 gallons a day (Collins, and others, 1930).

TIDE SPRING

An unusual spring of some interest is "Tide Spring", a periodic or ebbing and flowing spring about 4 miles southwest of Broadway. The water issues from a small valley in the upper Beekmantown dolomite. Only about twenty periodic springs are known in the United States but more probably exist (Meinzer, 1936). All such springs issue from limestone (or dolomite) and their periodic action is generally attributed to natural siphons in the rock. Such springs are not the same as ordinary intermittent springs which flow in wet seasons and cease in dry seasons. The cyclic action of Tide Spring was observed by the writer during August, 1958. Water bubbled upward from the bottom of the nearly empty spring basin until the basin overflowed and water ran down the spillway and formed a stream. After a time the inflow gradually ceased and the water-level dropped until the basin was nearly empty. A period of inactivity lasted 15 minutes or so and then water began to re-enter the basin. The entire cycle took approximately an hour. There are all types of variations on this cyclical action. The period of inactivity may be minutes, days, or even months. Active flowing may last for minutes, or days, and the rate of discharge may be more than 1,000 gallons a minute. In general, it appears that the largest discharges occur after the longest periods of inactivity. An automatic water-stage recorder was operated on Tide Spring from July, 1927 to August, 1932 and a copy of the record made is in Virginia Geological Survey Bulletin 45.

BEAR LITHIA SPRING

Lithia water is said to come out Bear Spring about 1.5 miles north of Elkton. The water emerges from gravels covering the bedrock, that is either Conococheague limestone or Elbrook dolomite, and flows west to South Fork of Shenandoah River. The rate of flow is about 1,440,000 gallons a day (Collins, and others, 1930).

OTHER SPRINGS NEAR ELKTON

Elkton (Kite) Spring, about 0.5 mile southeast of Elkton, issues from the Rome formation and is the source of water for the municipal water system. Samuel Spring, about 1 mile south of Elkton, issues from loose gravel in a stream valley at the foot of the Blue Ridge. The flow is more than 1 million gallons per day according to Collins, and others

TABLE 10—*Chemical Analyses of Spring Waters (from Collins, and others, 1930)*

Name	Flow in gallons per min.	APPROXIMATE PARTIAL ANALYSIS (PARTS PER MILLION)								
		Dissolved solids (Calculated)	Iron (Fe)	Calcium (Ca) (by turbidity)	Sodium (Na) (calculated)	Bicarbonate (HCO_3)	Sulphate (SO_4) (by turbidity)	Chloride (Cl)	Nitrate (NO_3)	Total hardness (as Ca CO_3)
Rawley Spring	48	28	13.78	1	....	17	6	0.2	....	33
Spring Creek (Patterson Spring)	4,000	164	.....	32	9	186	1	0.7	4.5	138
Silver Spring (Mill Pond Spring)	{3,000 / 4,000}	266	.....	45	less than 5	298	6	0.8	5.5	251
Massanetta Spring (Principal Spring)	400	296	.....	....	17	342	3	0.5	4.4	250
Warm Spring	500	296	.....	40	6	330	9	1.0	4.7	272
Lacey Spring	4,000	270	.....	100	7	292	10	1.7	6.9	243
Bear Lithia Spring	1,000	80	.....	24	6	86	5	0.3	0.5	63

(1930). The abundance of water that comes from the springs near Elkton gives some idea of the ground water potential of the area.

Cold Spring Pond

A large spring-fed pond about 2 miles north of Timberville is called Cold Spring Pond. The water issues from Edinburg limestone and the general structure of the area is synclinal. About 1 mile southeast of Cold Spring Pond is another large spring-fed pond in a syncline in the Edinburg limestone.

Sparkling Springs

Sparkling Springs is a small resort area about 2 miles west of Singers Glen. The water issues from steeply dipping Edinburg limestone on the east slope of Little North Mountain.

REFERENCES

Bassler, R. S., 1909, Cement resources of Virginia west of the Blue Ridge: Va. Geol. Survey Bull. 2-A, 309 pp.

Bick, Kenneth F., 1960, Geology of the Lexington Quadrangle, Virginia: Va. Division of Mineral Resources, Rept. of Invest. 1, 40 pp.

Bloomer, R. O., 1950, Late pre-Cambrian or Lower Cambrian formations in central Virginia; Am. Jour. Sci., vol. 248, no. 11, pp. 753-783.

————————, and Bloomer, R. R., 1947, The Catoctin formation in central Virginia: Jour., Geol. vol. 55, no. 2, pp. 94-106.

————————, and Werner, H. J., 1955, Geology of the Blue Ridge region in central Virginia: Geol. Soc. Amer. Bull., vol. 66, pp. 579-606.

Bowles, Oliver, 1960, Dimension Stone *in* Industrial Minerals and Rocks: Amer. Inst. of Mining, Metal. and Petrol. Eng., New York, pp. 321-337.

Brent, W. B., 1955, The geology of the Harrisonburg quadrangle, Virginia: unpubl. Ph.D. thesis, Cornell Univ.

————————, and Young, R. S., 1955, Klippen in the Harrisonburg quadrangle, Virginia (abs.): Geol. Soc. Amer. Bull., vol. 66, no. 12, pt. 2, pp. 1685-1686.

Brown, W. R., 1958, Geology and mineral resources of the Lynchburg quadrangle, Virginia: Va. Division of Mineral Resources, Bull. 74, 99 pp.

Butts, Charles, 1918, Geologic section of Blair and Huntingdon counties, central Pennsylvania: Am. Jour. Sci., 4th ser., vol. 46, pp. 523-537.

————————, 1933, Geologic map of the Appalachian Valley in Virginia: Va. Geol. Survey.

————————, 1940, Geology of the Appalachian Valley in Virginia: Va. Geol. Survey, Bull. 52, pt. 1, 568 pp.

————————, and Edmundson, R. S., 1939, The geology of Little North Mountain in northern Virginia: Va. Geol. Survey, Bull. 51-H, pp. 164-179.

Cady, R. C., 1936, Groundwater resources of the Shenandoah Valley, Virginia: Va. Geol. Survey, Bull. 45, 137 pp.

Campbell, M. R., 1899, U. S. Geol. Survey Atlas 90, Cranberry folio, p. 5.

——————, and others, 1925, The Valley coal fields of Virginia: Va. Geol. Survey Bull. 25, 322, pp.

Chadwick, G. H., 1908, Revision of the New York series: Science, new series, vol. 28, pp. 346-348.

——————, 1933, Hamilton red beds in eastern New York: Science, new series, vol. 77, pp. 86-87.

——————, 1936, History and value of the name "Catskill" in geology: New York State Museum, Bull. 307, 116 pp.

Chemical character of surface waters of Virginia, 1960: Division of Water Resources, Bull. 23.

Clarke, J. M., 1903, Classification of the New York series: New York State Museum Handbook 19, p. 21.

——————, and Schuchert, Charles, 1899, The nomenclature of the New York series of geological formations: Science, new series, vol. 10, pp. 874-878.

Clausen, C. F., 1960, Cement Materials: *in* Industrial Minerals and Rocks: Amer. Inst. of Mining, Metal., and Petrol. Eng., New York, pp. 203-231.

Collins, W. D., and Foster, M. D., Reeves, Frank, Meacham, R. P., 1930, Springs of Virginia: Va. Division of Water Resources and Power Bull. 1, 55 pp.

Conrad, T. A., 1842, Observations on the Silurian and Devonian systems of the U. S.: Phila. Acad. Nat. Sci. Jour., vol. 8, pt. 2, pp. 229-230.

Cooper, B. N., and Cooper, G. A., 1946, Lower Middle Ordovician stratigraphy of the Shenandoah Valley, Virginia: Geol. Soc. Amer. Bull.,vol. 57, pp. 35-114.

Cooper, B. N., and Prouty, C. E., 1943, Stratigraphy of the lower Middle Ordovician of Tazewell County, Virginia: Geol. Soc. Amer. Bull., vol. 54, pp. 819-886.

Currier, L. W., 1935, Zinc and lead region of southwestern Virginia: Va. Geol. Survey Bull. 43, 122 pp.

Darton, N. H., 1892, Notes on the stratigraphy of a portion of central Appalachian Virginia: Amer. Geologist, vol. 10, pp. 13, 17-18.

—————, 1894, Geologic Atlas of the U. S., Staunton folio, no. 14.

—————, 1896 a, Geologic Atlas of the U. S., Piedmont W. Va.-Md. folio, no. 28.

—————, 1896 b, Geologic Atlas of the U. S., Franklin, W. Va.-Va. folio, no. 32.

—————, 1899, Geologic Atlas of the U. S., Monterey, Va.-W. Va. folio, no. 61.

Edmundson, R. S., 1940, Origin of Little North Mountain in northern Virginia: Jour. Geol. vol. 48, pp. 532-551.

—————, 1945, Industrial limestones and dolomites in Virginia, northern and central parts of Shenandoah Valley: Va. Geol. Survey Bull. 65, 195 pp.

—————, 1958, Industrial limestones and dolomites in Virginia, James River district west of the Blue Ridge: Va. Division of Mineral Resources Bull. 73, 137 pp.

Fenneman, N. M., 1938, Physiography of the eastern United States: McGraw-Hill, 714 pp.

Geiger, H. R., and Keith, Arthur, 1891, The structure of the Blue Ridge near Harpers Ferry, Maryland-West Virginia: Geol. Soc. Amer. Bull., vol. 2, pp. 155-164.

Geologic Map of Virginia, 1928, Va. Geol. Survey.

Giles, A. W., 1927, The geology of Little North Mountain in northern Virginia and West Virginia: Jour. Geol., vol. 35, no. 1, pp. 32-57.

Gooch, E. O., Wood, R. S., and Parrott, W. T., 1960, Sources of aggregate used in Virginia highway construction: Va. Division of Mineral Resources, Min. Resources Report 1, 65 pp.

Hall, James, 1839, Third annual report of the fourth geological district of the state of New York: N. Y. Geol. Survey 3rd Ann. Rept. pp. 322-326.

Hammer, S., and Heck, E. T., 1941, A gravity profile across the central Appalachians, Buckhannon, West Virginia, to Swift Run Gap, Virginia: Amer. Geophysical Union Trans., 22nd Annual meeting, pp. 353-362.

Harder, E. C., 1910, Manganese deposits of the United States: U. S. Geol. Survey Bull. 427, 298 pp.

Hayes, C. W., 1891, The overthrust faults of the southern Appalachians: Geol. Soc. Amer. Bull., vol. 2, p. 143.

Hayes, Larry G., 1960, Bowers-Campbell mine, Timberville, Virginia: Paper presented at annual meeting of Amer. Institute of Mining, Metal., and Petrol. Eng., New York, Feb. 1960, 9 pp.

Herbert, Paul, and Young, R. S., 1956, Sulfide mineralization in the Shenandoah Valley of Virginia: Va. Division of Geology Bull. 70, 58 pp.

Howell, R. W., 1925, *in* Campbell and others, The valley coal fields of Virginia: Va. Geol. Survey Bull. 25, pp. 283-300.

Johnson, Douglas, 1931, Stream sculpture on the Atlantic slope, A study of the evolution of Appalachian Rivers: Columbia Univ. press, 142 pp.

Jonas, A. I., and Stose, G. W., 1938, Age relation of the pre-Cambrian rocks in the Catoctin Mountain—Blue Ridge and Mount Rogers anticlinoria in Virginia: Amer. Jour. Sci., vol. 237, pp. 575-593.

Keith, Arthur, 1893, *in* Williams, G. H., and Clark, W. B., Maryland; its resources, industries, and institutions, Baltimore.

____________________, 1894a, Geology of the Catoctin Belt: U. S. Geol. Survey, 14th Ann. Rept., pt. 2, pp. 285-395.

____________________, 1894b, Geologic Atlas of the U. S., Harpers Ferry, Va.—Md.—W. Va. folio, no. 10.

____________________, 1903, Geologic Atlas of the U. S.: Cranberry folio, no. 90, p. 5.

King, P. B., 1943, Manganese deposits of the Elkton area, Virginia: U. S. Geol. Survey Bull. 940-B, 55 pp.

____________________, 1950, Geology of the Elkton area, Virginia: U. S. Geol. Survey Prof. Paper 230, 82 pp.

Lesley, J. P., 1876, The Boyd's Hill gas well at Pittsburgh, Pennsylvania: Second Pennsylvania Geol. Survey, Rept. L, pp. 221-227.

Le Van, D. C., 1959, A review of oil and gas in Virginia: Virginia Minerals, vol. 5, no. 2, 7 pp.

Lowry, W. D., 1954, Silica sand resources of western Virginia: Va. Poly. Inst., Eng. Exper. Sta. Bull., ser. no. 96.

Mallet, J. W., 1874, *in* The Rawley Springs of Rockingham County, Va., with an analysis of the waters: Enquirer Steam Book and Job Printing House, Richmond, Va., 16 pp.

Martens, J. H. C., 1939, Petrology and correlation of deep-well sections in West Virginia and adjacent states: W. Va. Geol. Survey, vol. 11, pp. 30-35.

Meinzer, O. E., 1936, *in* Cady, R. C., Groundwater resources of the Shenandoah Valley, Virginia: Va. Geol. Survey Bull. 45, pp. 52-54.

________________, 1949, (Editor) Hydrology: Dover Publications, Inc., New York, 712 pp.

Metcalf, R. W., Calver, J. L., and Otte, Mary, 1958, The mineral industry of Virginia: U. S. Bureau of Mines, U. S. Dept. of Interior, and Va. Division of Mineral Resources, 23 pp.

Miller, R. L., and Brosgé, W. P., 1954, Geology and oil resources of the Jonesville district, Lee County, Virginia: U. S. Geol. Survey Bull. 990, 240 pp.

Miller, R. L., and Fuller, J. O., 1954, Geology and oil resources of the Rose Hill district—the fenster area of the Cumberland overthrust block—Lee County, Virginia: Va. Geol. Survey Bull. 71, 382 pp.

Price, P. H., 1942, Discovery of gas in Rockingham County, Virginia: Amer. Assoc. Petrol. Geol. Bull., vol. 26, p. 275.

Public water supplies in Virginia, 1939, Virginia Dept. of Health, Richmond.

Reed, J. C., 1955, Catoctin formation near Luray, Virginia: Geol. Soc. Amer. Bull. vol. 66, no. 7, pp. 871-896.

Resser, C. E., 1938, Cambrian system (restricted) of the southern Appalachians: Geol. Soc. Amer. Special Paper 15, 140 pp.

Rice, K. A., 1959, Climates of the states, Virginia: Climatography of the United States, Weather Bureau, U. S. Dept. of Commerce.

Ries, H., and Somers, R. E., 1920, The clays and shales of Virginia west of the Blue Ridge: Va. Geol. Survey Bull. 20, 118 pp.

Rogers, W. B., 1884, A reprint of annual reports and other papers on the geology of the Virginias: New York, 832 pp. (Reports originally published, 1835-1841).

Safford, J. M., 1856, A geological reconnaissance of the state of Tennessee: Tennessee Geol. Survey, 1st Bienn. Rept., 164 pp.

__________, 1869, Geology of Tennessee: Nashville, 550 pp.

Schrader, F. C., Stone, R. W., and Sanford, S., 1917, Usef l minerals of the United States: U. S. Geol. Survey Bull. 624, 412 pp.

Spencer, A. C., 1897, The geology of Massanutten Mountain in Virginia: private publication of Ph.D. dissertation, Johns Hopkins Univ., 54 pp.

Stose, A. J., and Stose, G. W., 1946, Geography of Carroll and Frederick counties: Maryland Dept. Geol., Mines, and Water Res., Carroll and Frederick Counties Rept., pp. 1-10.

Stose, G. W., 1906, The sedimentary rocks of South Mountain, Pennsylvania: Jour. Geol., vol. 14, pp. 201-220.

__________, 1908, The Cambro-Ordovician limestones of the Appalachian Valley in southern Pennsylvania: Jour. Geol., vol. 16, pp. 698-714.

__________, 1940, Age of the Schooley peneplain: Amer. Jour. Sci., vol. 238, pp. 461-476.

__________, 1942, Source beds of manganese ore in the Appalachian Valley: Econ. Geol., vol. 37, no. 3, pp. 163-172.

Stose, G. W., Miser, H. D., Katz, F. J., and Hewett, D. F., 1919, Manganese deposits of the west foot of the Blue Ridge, Virginia: Va. Geol. Survey Bull. 17, 166 pp.

Surface water supply of the United States, 1957, Pt. 1-B, North Atlantic slope basins, New York to York River: U. S. Geological Survey Water-Supply Paper 1502.

Swartz, C. K., and others, 1913, Lower Devonian: Maryland Geol. Survey, p. 85.

Swartz, F. M., 1929, The Helderberg group of parts of West Virginia and Virginia: U. S. Geol. Survey, Prof. Paper 158c, pp. 27-75.

Taylor, R. C., 1855, Statistics of coal: Philadelphia.

Thornton, C. P., 1953, The geology of the Mt. Jackson quadrangle, Virginia: Unpublished Ph.D. dissertation, Yale Univ.

Ulrich, E. O., 1911, Revision of the Paleozoic systems: Geol. Soc. Amer. Bull., vol. 22, pp. 281-680.

Watson, T. L., 1907, Mineral resources of Virginia: Virginia Jamestown Exposition Commission, Lynchburg, Va., 618 pp.

Whittington, H. B., 1956, Silicified Middle Ordovician trilobites: The Odontopleuridae: Harvard Museum of Comparative Zoology Bulletin, vol. 114, no. 5, pp. 155-288; 24 plates.

Whittington, H. B., 1959, Silicified Middle Ordovician trilobites: Remopleurididae, Trinucleidae, Raphiophoridae, Endymioniidae: Harvard Museum of Comparative Zoology Bulletin, vol. 121, no. 8, pp. 371-496; 36 plates.

Whittington, H. B., and Evitt, W. R., 1953, Silicified Middle Ordovician trilobites: Geol. Soc. Amer. Memoir 59, 137 pp.

Willard, Bradford, 1939, The Devonian of Pennsylvania: Penn. Geol. Survey, 4th ser., Bull. G19, p. 149.

Wilmarth, M. G., 1938, Lexicon of geologic names of the United States: U. S. Geol. Survey Bull. 896, 2396 pp.

Wilson, J. L., 1952, Upper Cambrian stratigraphy in the central Appalachians: Geol. Soc. Amer. Bull., vol. 63, pp. 275-322.

Woodward, H. P., 1941, Silurian system of West Virginia: West Virginia Geol. Survey, 326 pp.

——————, 1943, Devonian system of West Virginia, West Virginia Geol. Survey, 655 pp.

——————, 1955, in Guidebook, Joint Field Conference, Harrisonburg area, Virginia: Appal. Geol. Society, Va. Division of Geol., W. Va. Geol. Survey, 44 pp.

Wright, F. J., 1925, The physiography of the upper James River basin in Virginia: Va. Geol. Survey Bull. 11, 67 pp.

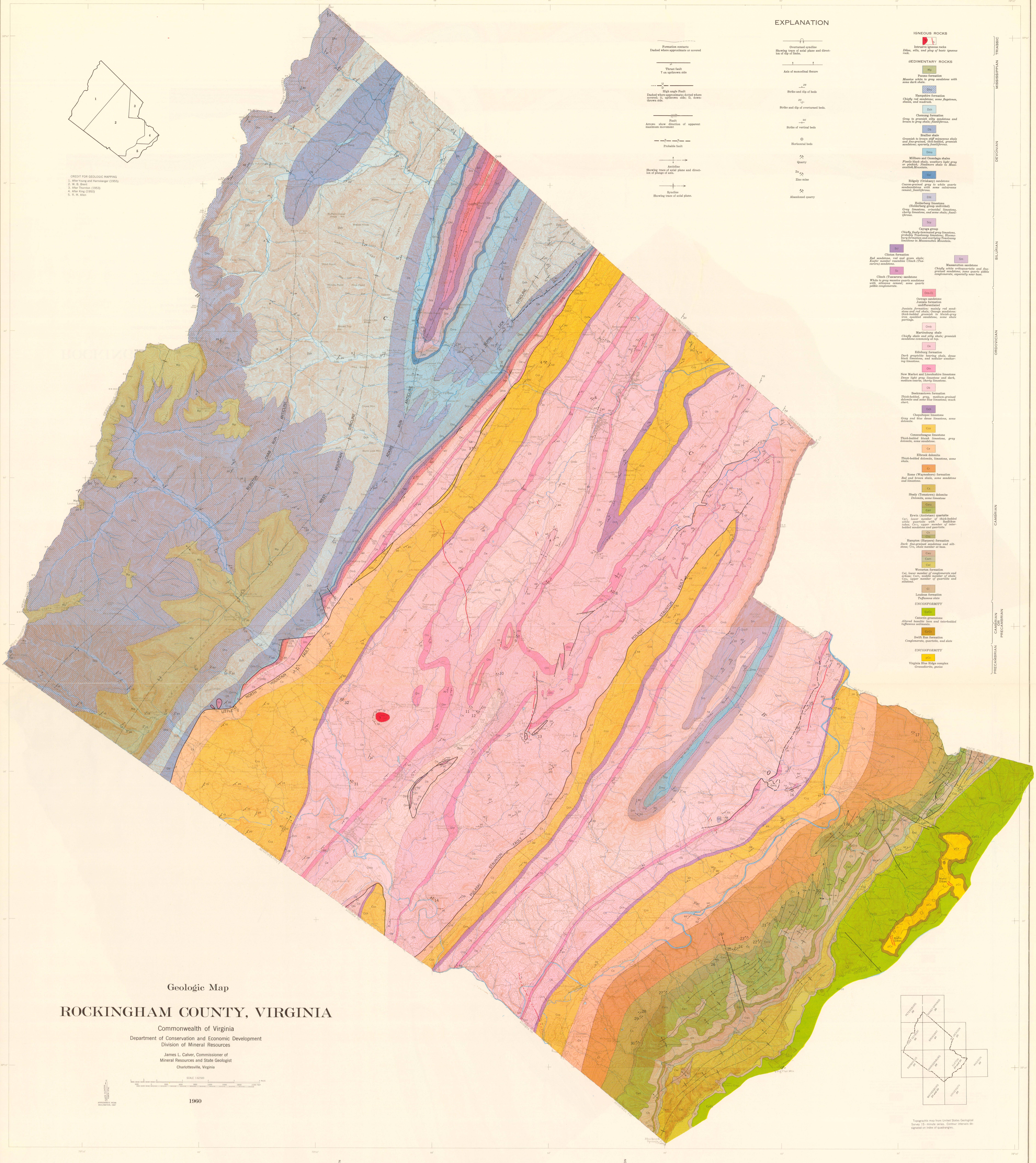
——————, 1934, The newer Appalachians of the South; pt. 1, Between the Potomac and the New Rivers: Denison Univ. Bull., vol. 34, pp. 1-105.

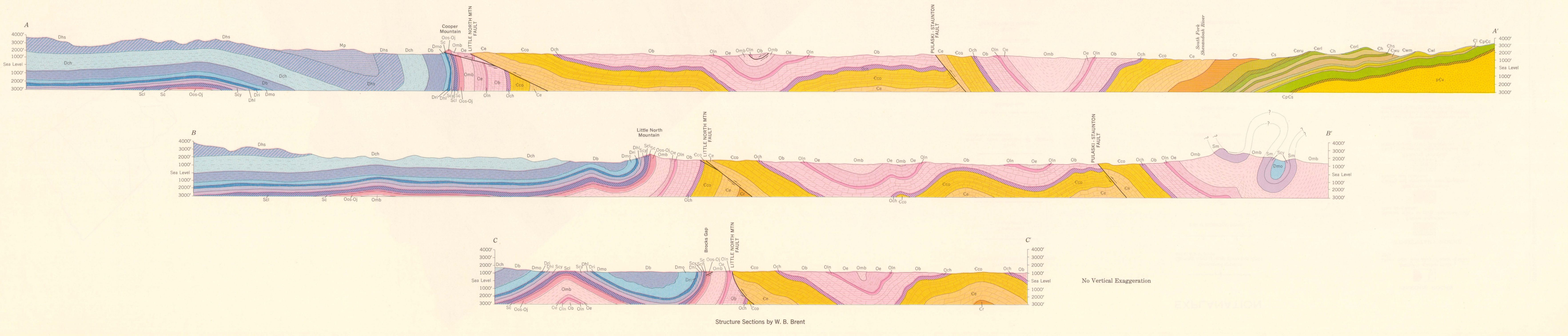
Young, R. S., 1954, The Geology of the Edinburg, Virginia-West Virginia quadrangle: unpublished Ph.D. thesis, Cornell Univ.

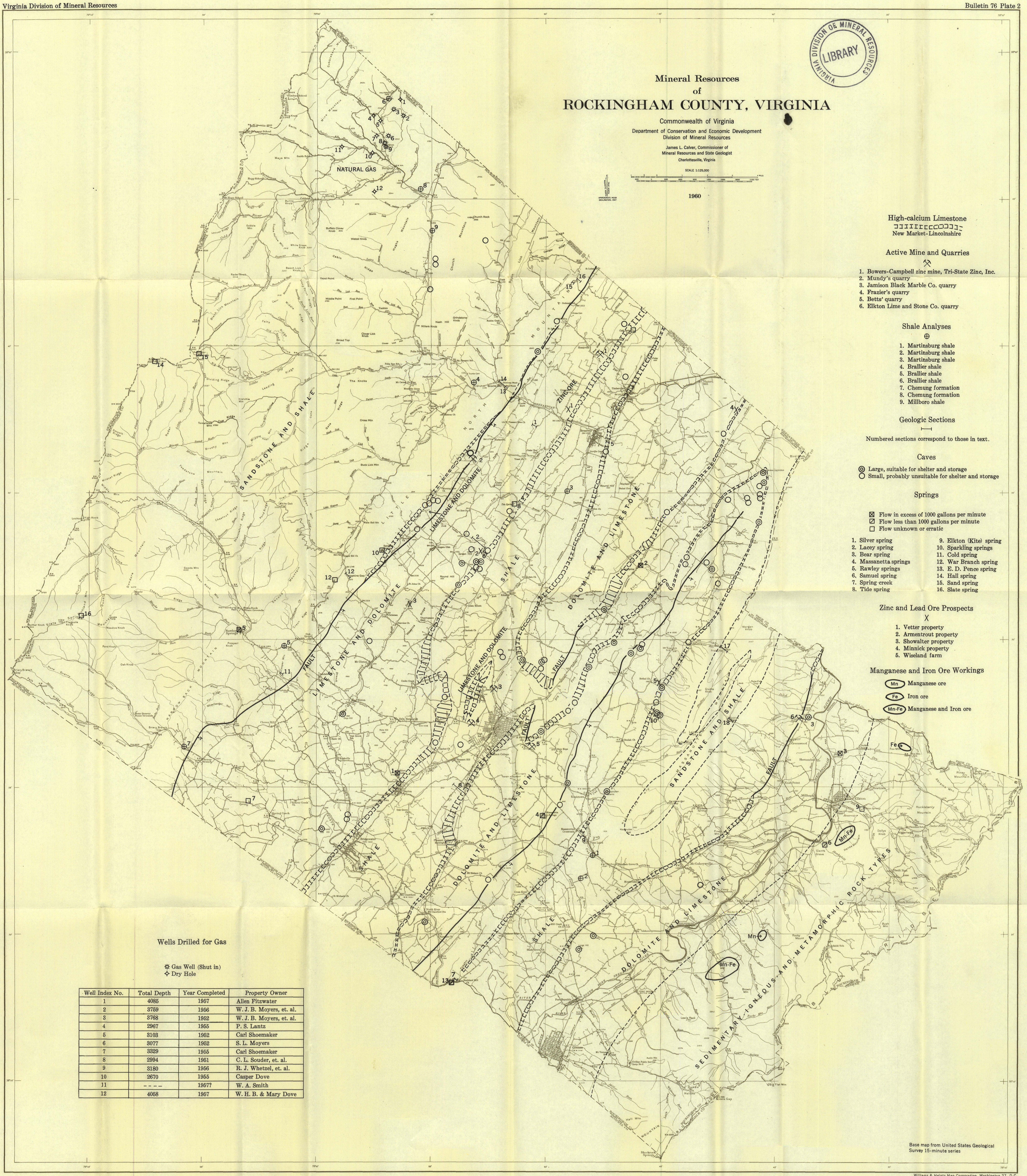
Young, R. S., and Harnsberger, W. T., 1955, Geology of Bergton gas field Rockingham County, Virginia: Amer. Assoc. Petrol. Geol. Bull., vol. 39, pp. 317-328.

SUBJECT INDEX

INDEX TO FOSSIL NAMES

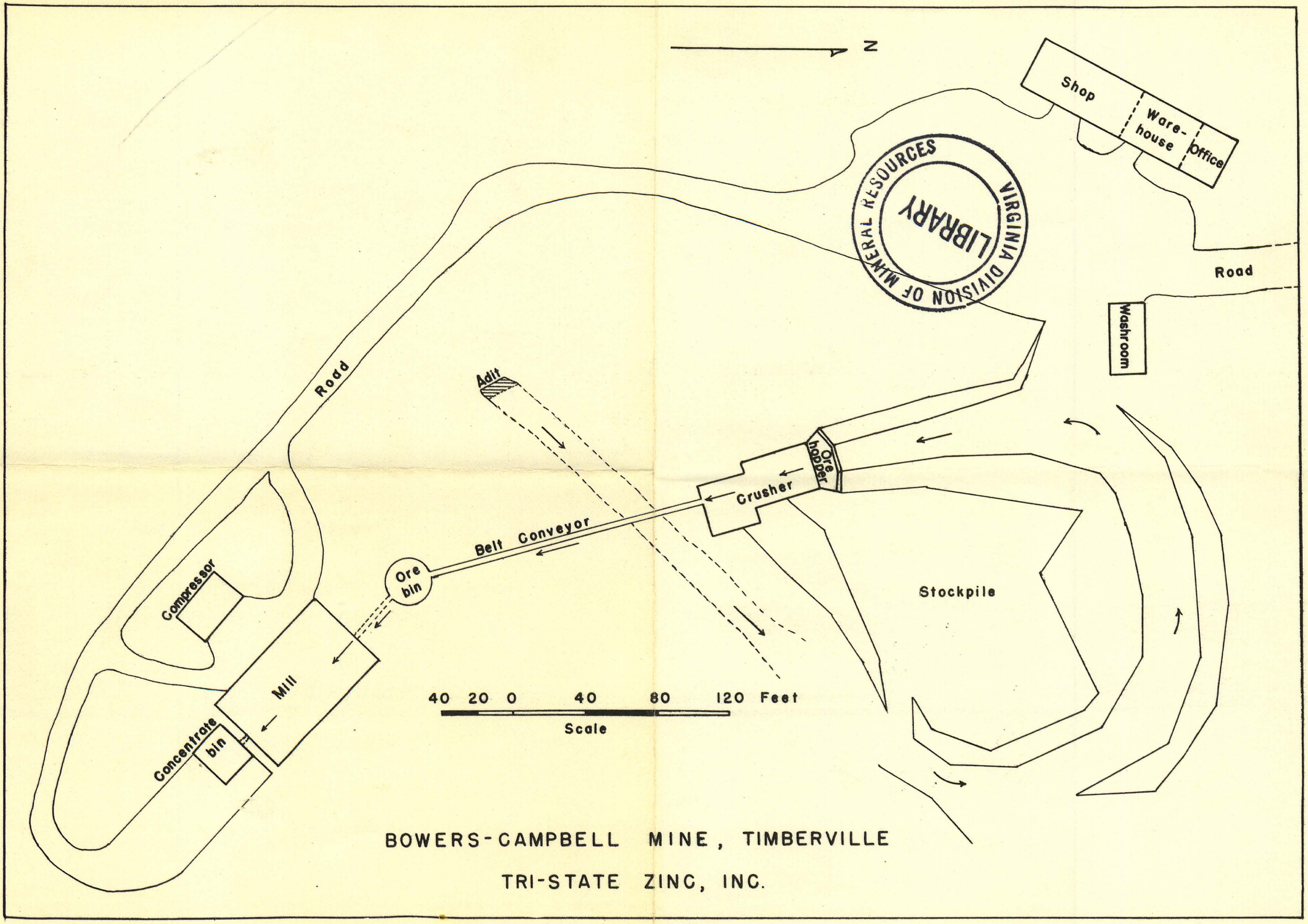

Geologic Map
ROCKINGHAM COUNTY, VIRGINIA
Commonwealth of Virginia
Department of Conservation and Economic Development
Division of Mineral Resources
James L. Calver, Commissioner of
Mineral Resources and State Geologist
Charlottesville, Virginia
SCALE 1:62500
APPROXIMATE MEAN DECLINATION, 1947
1960
CREDIT FOR GEOLOGIC MAPPING
1. After Young and Harnsberger (1955)
2. W. B. Brent
3. After Thornton (1953)
4. After King (1950)
5. R. M. Allen
EXPLANATION
IGNEOUS ROCKS
Intrusive igneous rocks
Dikes, sills, and plug of basic igneous rock.
TRIASSIC
SEDIMENTARY ROCKS
Mp
Pocono formation
Massive white to gray sandstone with some dark shale.
MISSISSIPPIAN
Dhs
Hampshire formation
Chiefly red sandstone; some flagstones, shales, and mudrock.
Dch
Chemung formation
Gray to greenish silty sandstone and brown to gray shale; fossiliferous.
Db
Brallier shale
Greenish to brown stiff micaceous shale and fine-grained, thin-bedded, greenish sandstone; sparsely fossiliferous.
Dmo
Millboro and Onondaga shales
Fissile black shale, weathers light gray or pinkish; Needmore shale in Massanutten Mountain.
Dri
Ridgely (Oriskany) sandstone
Coarse-grained gray to white quartz sandsandstone with some calcareous cement; fossiliferous.
Dhl
Helderberg limestone
(Helderberg group undivided)
Gray limestone, crinoidal limestone, cherty limestone, and some shale; fossiliferous.
DEVONIAN
Scy
Cayuga group
Chiefly finely-laminated gray limestone, probably Tonoloway limestone; Bloomsburg formation and overlying Tonoloway limestone in Massanutten Mountain.
Scl
Clinton formation
Red sandstone, red and green shale; Keefer member resembles Clinch (Tuscarora) sandstone.
Sc
Clinch (Tuscarora) sandstone
White to gray massive quartz sandstone with siliceous cement; some quartz pebble conglomerate.
Sm
Massanutten sandstone
Chiefly white orthoquartzite and fine-grained sandstone; some quartz pebble conglomerate, especially near base.
SILURIAN
Oos-Oj
ORDOVICIAN
CAMBRIAN
UNCONFORMITY
UNCONFORMITY
CAMBRIAN OR PRECAMBRIAN
PRECAMBRIAN
PARNASSUS 20
HARRISONBURG 20
ELKTON 20 and 50
MADISON 50
WAYNESBORO 20 and 50
UNIVERSITY 20
Topographic map from United States Geological Survey 15-minute series. Contour intervals designated on index of quadrangles.
38°50′
45′
38°15′
79°10′
05′
79°00′
35′
78°30′


A
A′
Cooper Mountain
LITTLE NORTH MTN FAULT
PULASKI-STAUNTON FAULT
B
B′
Little North Mountain
C
C′
4000′
3000′
2000′
1000′
Sea Level
1000′
2000′
3000′
No Vertical Exaggeration
Structure Sections by W. B. Brent



Well Index No.	Total Depth	Year Completed	Property Owner
1	4085	1957	Allen Fitzwater
2	3759	1956	W. J. B. Moyers, et. al.
3	3768	1952	W. J. B. Moyers, et. al.
4	2967	1955	P. S. Lantz
5	3103	1952	Carl Shoemaker
6	3077	1952	S. L. Moyers
7	3329	1955	Carl Shoemaker
8	2994	1951	C. L. Souder, et. al.
9	3180	1956	R. J. Whetzel, et. al.
10	2670	1955	Casper Dove
11	----	1957?	W. A. Smith
12	4058	1957	W. H. B. & Mary Dove

Williams & Heintz Map Corporation, Washington 27, D.C.



BOWERS-CAMPBELL MINE, TIMBERVILLE

TRI-STATE ZINC, INC.