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COMMONWEALTH OF VIRGINIA

DEPARTMENT OF CONSERVATION AND DEVELOPMENT

VIRGINIA DIVISION OF MINERAL RESOURCES

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

Bulletin 73

Industrial Limestones and Dolomites in Virginia:

James River District West of the Blue Ridge

By

RAYMOND S. EDMUNDSON

CHARLOTTESVILLE, VIRGINIA

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Commonwealth of Virginia
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Richmond
1958

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COMMONWEALTH OF VIRGINIA

DEPARTMENT OF CONSERVATION AND DEVELOPMENT

DIVISION OF MINERAL RESOURCES

CHARLOTTESVILLE, VIRGINIA

March 24, 1958

To the Department of Conservation and Development:

GENTLEMEN:

I have the honor to transmit and recommend for publication as Bulletin 73 of the Division of Mineral Resources the manuscript and illustrations of a report on *Industrial Limestones and Dolomites in Virginia: James River District West of the Blue Ridge,* by Dr. Raymond S. Edmundson, Department of Geology, University of Virginia.

This is the fourth report in a series on the industrial limestones and dolomites in the State. It contains a discussion of these carbonate rocks in an area of approximately 2100 square miles in the James River drainage basin. The southern boundary of this area ties in closely with Bulletin 62 by Dr. B. N. Cooper, and the northern boundary with Bulletin 65 by Dr. Edmundson, published in 1944 and 1945, respectively.

The geologic data given in this report are primarily of industrial significance, with discussion of the stratigraphy and structure of the formations, measured geologic sections, and analyses of carefully selected field samples.

Respectfully submitted,
JAMES L. CALVER
Commissioner

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

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Industrial Limestones and Dolomites in Virginia: James River District West of the Blue Ridge

By Raymond S. Edmundson

ABSTRACT

The area described in this report is approximately 2,100 square miles or about two-thirds of the James River drainage basin west of the Blue Ridge. Natural boundaries include the Blue Ridge on the southeast and a part of Allegheny Mountain along the West Virginia-Virginia line. The southern boundary ties in closely with the area described in a report by Dr. B. N. Cooper (1944) entitled *New River-Roanoke District*, the first in the series of publications on the industrial limestones and dolomites in Virginia. The James River district on the north joins the area previously described by the writer (1945) in the second report of the series entitled *Northern and Central Parts of Shenandoah Valley*.

The James River district contains deposits of high-calcium limestone averaging about 97 percent calcium carbonate. The New Market limestone, where free of chert, and the Murat facies of the Lincolnshire limestone are the important high-calcium limestones in the southeastern part of the district. Quarryable thicknesses of the New Market occur also near the southwestern end of Warm Springs Valley. Other formations, locally containing units of high-calcium limestone, comprise a part of the Helderberg group in the central and western parts of the district.

Extensive exposures of Shady dolomite, containing more than 42 percent magnesium carbonate, are described from the general vicinity of Natural Bridge Station and Buchanan in Rockbridge and Botetourt counties. Most of the sampled dolomite units in the Waynesboro, Elbrook, Conococheague, and Beekmantown formations contains less than 40 percent magnesium carbonate.

Special study was made of the carbonate rocks suitable for chemical use and favorably located near railroads. Limestones, containing less than 95 percent calcium carbonate, were studied locally in some detail. Descriptions of the belts of industrial limestone and dolomite are supplemented by a geologic map, sections, physical tests, and chemical analyses.

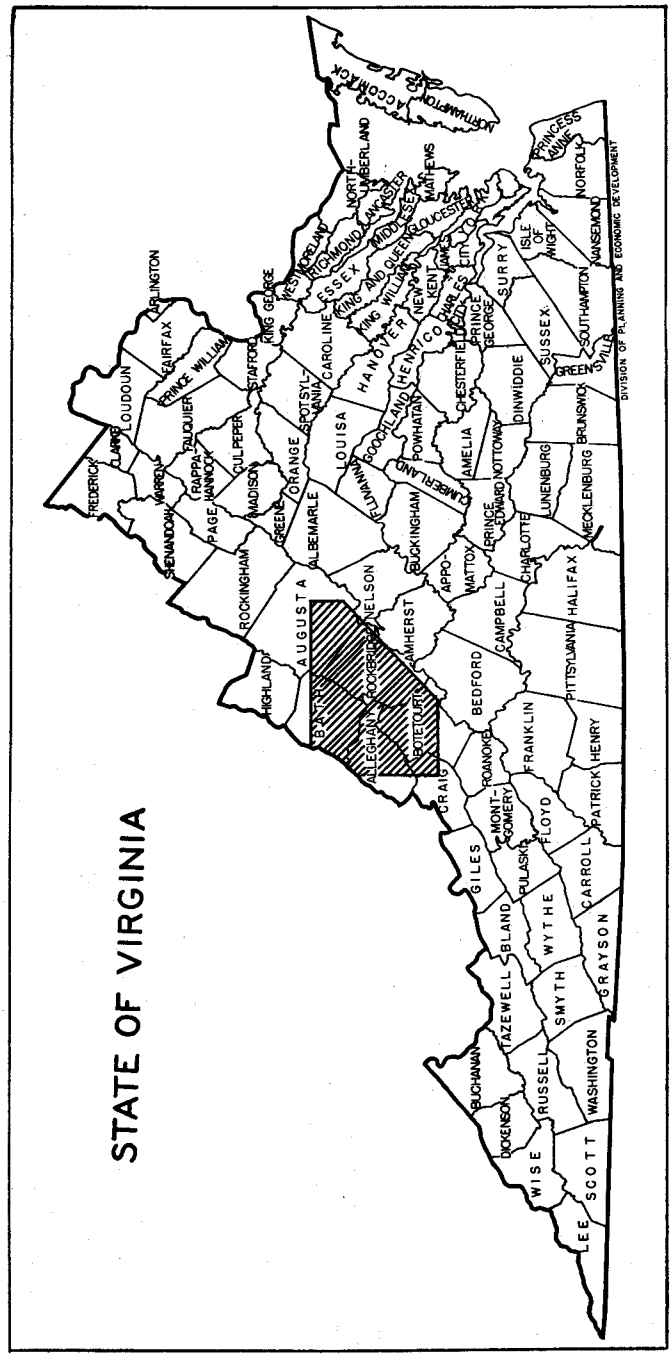

FIGURE 1

Area of investigation (shaded) includes portions of Augusta, Bath, Alleghany, Rockbridge, Craig and Botetourt counties.

INTRODUCTION

Location of the District

The most important deposits of limestone and dolomite in Virginia are in the Ridge and Valley province. This natural division of the State, west of the Blue Ridge, may be defined as a long relatively narrow belt of ridges and valleys underlain by folded Paleozoic strata. It is divided longitudinally into two parts: an eastern broad almost flat valley with local ridges and hills, and a western belt of narrow parallel ridges and valleys. The eastern belt (Stose et al., 1919, p. 7-11) known as the Valley of Virginia, is further subdivided, from north to south, into Shenandoah, Fincastle, Salem, Dublin, and Abingdon valleys. The area described in this report (Fig. 1) lies within the James River drainage basin, including a part of the western belt of narrow ridges and valleys, the southern portion of Shenandoah Valley, and Fincastle Valley. It has an area of approximately 2,100 square miles or about two-thirds of the entire James River drainage basin west of the Blue Ridge.

Natural boundaries include the Blue Ridge on the southeast and a part of Allegheny Mountain along the West Virginia-Virginia line northwest of Callaghan and Mountain Grove. The southern boundary ties in closely with the area described in a report by Dr. B. N. Cooper (1944) entitled New River-Roanoke District, the first in the series of publications on the industrial limestones and dolomites in Virginia by the Virginia Geological Survey. The James River district on the north joins the area previously described by the writer in a report (1945), the second in the series of industrial limestones and dolomites, entitled Northern and Central Parts of Shenandoah Valley.

Purpose and Scope of Report

It is the main purpose of this report to give information on the location, thickness, and chemical composition of the important occurrences of limestones and dolomites in the James River district west of the Blue Ridge, Virginia. In addition, the report contains a few physical tests of the rocks which were made by the Division of Tests, Virginia Department of Highways.

The information in this paper should be helpful to quarry operators and others interested in the expansion of the stone industry. Spe-

cial study was made of those mappable units which contain high-calcium limestone and high-magnesium dolomite. The physical character and chemical composition of the impure carbonate rocks at a few selected localities are discussed.

The introductory part of the report contains a summary of the geologic column, geologic structures, and tentative correlations of the formations. The rocks are mapped (Pl. 1) as lithologic units composed of rocks of similar composition, such as limestone, or rocks more or less uniformly varied in character, as an alternation of limestone and dolomite or limestone and shale. All of the units mapped, except for the belt of high-magnesium dolomite, include two or more geologic formations.

It is thought that the data in this paper are adequate to outline the most important belts of carbonate rocks and to serve as a guide in selecting particular localities for more detailed geologic investigation and testing.

Field Work and Acknowledgments

In 1942 a study of the industrial limestones and dolomites in the Appalachian Valley of Virginia was planned by the State Geologist. The area northeast of Roanoke was assigned to the writer and the area southwest of Roanoke to Dr. Byron N. Cooper, then geologist with the Virginia Geological Survey. This report is the fourth in the series on the limestones and dolomites of present and future industrial value in the State.

Most of the field work was done jointly with Dr. Byron N. Cooper during the summer of 1945. The survey was continued by the writer for three weeks in 1946 and for about two weeks in 1956. The report, including the geologic sections and map, was prepared by the writer. Samples collected during the field investigations were analyzed by Froehling and Robertson, Inc., Richmond, Virginia, and by Dr. John H. Yoe of the University of Virginia, also chemist with the Virginia Geological Survey. Wherever possible, rock chips for analyses were collected from fresh material at stratigraphic intervals of 1 to 2 feet. This is believed to yield the average composition of the full thickness of the rock sampled.

The geologic map (Butts, 1933) of the Appalachian Valley of Virginia served as a guide for all of the field investigations. Only minor changes, made locally along the belts of high-calcium limestone and high-magnesium dolomite that were studied in detail are incorporated

in the map accompanying this report (Pl. 1). In addition to this acknowledgment, many salient features of the geology discussed in this report are taken from Virginia Geological Survey Bulletin 52, which is complementary to the geologic map of the Appalachian Valley.

The belt of high-magnesium dolomite and associated structure along the southeastern boundary of the district southwest of Buena Vista was sketched from a manuscript map made by Dr. Robert O. Bloomer for the Virginia Geological Survey. The writer has used also manuscript maps by Dr. Herbert P. Woodward which are in the files of the Division of Mineral Resources. These maps give the geology of the Natural Bridge and Eagle Rock quadrangles. The base maps used during the survey include county maps prepared by the Virginia Department of Highways and quadrangle topographic maps of the U. S. Geological Survey. Although different mappable units are shown on Plate 1 from what appears on the Geological Map of the Appalachian Valley, the boundaries are essentially the same, and the reader will understand that the writer makes little pretense to originality.

The writer is indebted to members of the Virginia Geological Survey for suggestions concerning the preparation of this report and for editing the manuscript and illustrations for publication. Special acknowledgment is due quarry operators for assistance in field investigations and for valuable information on special uses of limestone and dolomite. To Mr. Shreve Clark, Testing Engineer, and Mr. W. T. Parrott, Engineering Geologist, of the Virginia Department of Highways the writer wishes to acknowledge their cooperation in furnishing data on physical tests of the rocks cited. Many citizens of the district have helped in the collection of data and have extended every courtesy to the writer.

Definition of Terms

Carbonate rocks are of sedimentary origin and are composed essentially of calcium carbonate or calcium and magnesium carbonates. They range in color from white through pale shades of gray, blue, and brown to black. In this report, particularly in the geologic sections, the term *limestone* is used in the general sense of applying to rocks composed predominantly of calcium carbonate ($CaCO_3$). *Dolomite* is used in the same sense for those rocks composed chiefly of the double carbonate of calcium and magnesium ($CaCO_3 \cdot MgCO_3$). A pure dolomite contains about 46 percent magnesium carbonate and 54 percent calcium carbonate. None of the carbonate rocks in Virginia have

this theoretical purity. Rocks containing about 10 to 30 percent magnesium carbonate are referred to in this report as *magnesian* or *dolomitic limestone*. If sufficient chemical data are available, the rocks are further subdivided into *high-calcium limestone*, containing more than 95 percent calcium carbonate, and *high-magnesium dolomite*, containing more than 40 percent magnesium carbonate and generally less than 4 percent noncarbonates. Since the noncarbonate constituents are important for certain uses, *impure limestone* is used in the text to describe those limestone formations which are commonly low in magnesium carbonate and contain more than 5 percent noncarbonates. These noncarbonates, or impurities, include chiefly silica, alumina, and iron oxide. Phosphorous, sodium, and potassium are generally present in very small amounts.

The descriptive terms *fine-*, *medium-*, and *coarse-grained* refer to the texture of the rocks. *Fine-grained* varieties are composed of mineral grains too small to be distinguished without magnification. The *coarse-grained* rocks are composed largely of particles, perhaps averaging not less than 2 millimeters in diameter, which are readily distinguished by the naked eye. Other rocks which show intermediate granularity are described as *medium-grained*. The term *compact* refers to a very fine-grained, dense, homogenous rock which breaks with a smooth fracture, similar to glass.

The color adjectives, unless otherwise designated, refer to the color of freshly broken rock surfaces.

Uses of Limestone and Dolomite

Certain uses of limestone and dolomite are dependent upon their chemical composition, whereas other uses are largely controlled by their physical character. Uses (Bowles and Banks, 1933, p. 7-11) in which physical properties are most important include dimension stone, concrete aggregate, road stone, railroad ballast, asphalt filler, riprap, sewage filter beds, stucco and terrazzo, poultry grit, sand, roofing gravel, yard and playground surface, concrete-block manufacture, whiting, and whiting substitute.

The important uses of carbonate rocks which are determined chiefly by their chemical composition are given in Table 1, compiled from a report (Lamar and Willman, 1938) of the Illinois State Geological Survey. The classification of limestones and dolomites given in this table is used in the general sense described under the definition of terms.

TABLE 1.—IMPORTANT CHEMICAL USES OF LIMESTONE AND DOLOMITE

USES	High-calcium limestone	Limestone and impure limestone	Magnesian limestone and dolomite	High-magnesium dolomite
Agricultural limestone	X	X	X	X
Alkalies	X			
Aluminum	X			
Ammonia (cyanamide process)	X			
Baking powders	X			
Calcium carbide	X			
Calcium nitrate	X			
Carbon dioxide	X	?	?	X
Coal-mine dusting	X		X	X
Dolomite refractories			?	X
Dye works	X			
Epsom salts				X
Explosives	X	X	X	X
Fertilizers	X			X
Flux:				
Open-hearth furnace	X			
Blast furnace	X		X	X
Nonferrous metals	X			
Glass manufacture	X			X
Lime:				
High-calcium	X			
Low-magnesium			X	
High-magnesium				X
Hydraulic		X		
Magnesium				X
Mineral feeds	X			
Natural cement		X		
Paper:				
Sulphite pulp (Tower system)	X			X
Sulphite pulp (milk-of lime system)				X
Soda pulp and sulphate pulp	X			
Portland cement	X	X		
Rock wool	X	X	X	X
Salt refining	X			
Soap purification	X			
Sugar refining	X			
Technical carbonate				X
Whiting substitute[a]	X			X

[a]Physical properties more important for certain uses.

The value of limestone, including crushed and broken stone (Metcalf, R. W., 1955, p. 9) and lime (Metcalf, R. W., 1955, p. 7) produced in Virginia in 1955, as given by the U. S. Bureau of Mines, is summarized in Tables 2 and 3.

TABLE 2.—LIMESTONE (CRUSHED AND BROKEN STONE) SOLD OR USED BY PRODUCERS IN VIRGINIA IN 1955

	Short tons	Value
Riprap	404	$ 404.00
Fluxing stone	547,182	845,515.00
Crushed stone:		
Concrete and road metal	4,519,086	6,034,403.00
Railroad ballast	348,871	408,460.00
Agriculture	585,165	1,134,031.00
Miscellaneous	3,711,662	5,728,580.00
Total	9,712,370	$ 14,151,393.00

TABLE 3.—LIME (QUICK AND HYDRATED) SOLD BY PRODUCERS IN VIRGINIA IN 1955

	Short tons	Value
Agricultural	26,945	$ 333,464.00
Building	4,355	52,034.00
Chemical and other industries	462,993	4,663,199.00
Total	494,293	$ 5,048,697.00

GEOGRAPHY

Relief and Drainage

The Appalachian Valley, described by Fenneman (1938, p. 195) as the "Ridge and Valley Province," is bounded on the east by the Blue Ridge and on the west by the Appalachian Plateaus and extends northeast and southwest far beyond the boundaries of Virginia. The eastern escarpment of the Plateau section lies west of the James River basin, but is represented in the extreme southwestern part of the State.

The Appalachian Valley which includes the headwaters of the James is divided longitudinally into two divisions, the Great Valley on the southeast and a wide belt with linear parallel ridges separated by narrow valleys on the northwest. Except for a few tributaries which rise in Monroe County, West Virginia, the James River basin is entirely within Virginia—the divide on the northwest being along the Virginia-West Virginia boundary and extending from the headwaters of Back Creek in northern Highland County southwestward to the vicinity of Mountain Lake in Giles County. The northern boundary of the basin within the Appalachian Valley extends in a southeasterly direction from Allegheny Mountain in Highland County to the Blue Ridge in southern Augusta County, passing near Hightown, Doe Hill, Elliott Knob, North Mountain Station, and Lofton. The southern boundary is irregular, but extends in an easterly direction from Mountain Lake in Giles County to the Blue Ridge in Botetourt County, following for the most part the crests of Johns, Sinking Creek, Brush, and Catawba mountains.

The total area of the James River basin west of the Blue Ridge is estimated to be about 3,100 square miles; that portion of the basin, here described as the James River district (Pl. 1), is about 2,100 square miles. That part of the drainage basin not described in this report includes the area north of Mountain Grove in Bath, Highland, and Augusta counties; and south of Fincastle in Craig and Botetourt counties.

The Great Valley occupied by the James River and its tributaries is a broad lowland ranging in altitude from about 2,000 feet along the James-Shenandoah divide between Lofton and Little North Mountain to about 700 feet at Balcony Falls where the river flows through the Blue Ridge. Most of the summits of the low rounded hills on the valley-floor in the vicinity of Natural Bridge range from 1,200 to 1,400 feet. North of Buffalo Creek the average width of the valley

is about 12 miles, but to the southwest it narrows rapidly to only about 2 miles in the vicinity of Buchanan. Stose and Miser (1922, p. 7) have suggested that although the valley between Lofton and Buchanan is drained by the James River, it is topographically continuous with that part of the valley drained northeastward by Shenandoah River and could therefore be considered a part of Shenandoah Valley. Conspicuous land forms which rise far above the general altitude of the surrounding valley are Big and Little House mountains northwest of Lexington and Short Hills, a narrow ridge extending from the vicinity of Murat southwestward to Purgatory Creek north of Buchanan.

Southwest of Purgatory Mountain the valley again widens to a rectangular area about 10 to 12 miles wide and 18 miles long. Only a few rounded summits, such as Timber Ridge, Cedar Ridge, and Rich Hill rise above 1,500 feet. Most of the valley region, except near the James which is entrenched several hundred feet below the valley floor, is between 1,000 and 1,500 feet. Altitudes of 1,500 feet or less are not restricted to the valley portion of the James River district. The 1,500 foot contour may be followed for many miles in the central part of the Ridge and Valley section along Craigs Creek to a point south of Newcastle, along Cowpasture River to northern Bath County, and along Jackson River for several miles north of Covington, Alleghany County.

The northwestern belt of the Appalachian Valley, characterized by alternating narrow ridges and valleys, extends from the western margin of the Great Valley northwestward to the Allegheny Front, the conspicuous escarpment defining the eastern limits of the Appalachian Plateaus. Prominent ridges, all trending in a northeasterly direction, from west to east along the James-Potomac divide are Allegheny, Lantz, Back Creek (Monterey), Jack, Bull Pasture, Shenandoah, Great North, and Little North mountains. The highest altitudes, exceeding 4,600 feet, are along the crest of Allegheny Mountain at the Virginia-West Virginia boundary in western Highland County. Altitudes greater than 4,000 feet occur also at isolated localities along Monterey, Jack, Shenandoah, and Great North mountains. Elliott Knob with an altitude of 4,473 feet is the highest point on any of the ridges bordering the Great Valley, except for Allegheny Mountain. Most of the valley ridges have summit areas which average between 3,000 and 3,500 feet. The maximum relief of the James River basin, i.e. the difference between the highest and lowest points, is approximately 4,000 feet.

All of the district is drained in an easterly direction by James

River and its tributaries. A few of the important tributaries shown on Plate 1 are Potts, Craig, and Catawba creeks southwest of Covington and Eagle Rock; Jackson and Cowpasture rivers in the northwestern part of the Ridge and Valley section; and Maury (North) River which rises in the valley ridges, flows through Goshen Pass, and thence across the Great Valley to join the James in the vicinity of Balcony Falls. Hydrographers give the drainage area of the Jackson River at Covington as 440 square miles and for the James at Buchanan as 2,060 square miles.

Transportation Facilities

The James River district is served adequately by two important railways and by a number of state and federal highways. The Norfolk and Western Railway extends northward across the eastern part of the district, passing through Buchanan and Buena Vista and thence northward through Shenandoah Valley. The Chesapeake and Ohio Railway enters Virginia in western Alleghany County and extends in an easterly direction across the area. At Clifton Forge it is divided into two lines: the northern route passing into the Piedmont Province via Goshen, Staunton, and Waynesboro; whereas the southern route, or James River division, closely parallels the course of James River and passes through the Blue Ridge at Balcony Falls. Branch lines of the Chesapeake and Ohio Railway also serve Hot Springs, Bath County, and Lexington, Rockbridge County.

U. S. Highway 11, the main thoroughfare through the Valley of Virginia, extends southwestward through Greenville, Lexington, and Buchanan. Other federal highways include U. S. Highway 60 which crosses the district in a northwesterly direction, passing through Buena Vista, Lexington, Clifton Forge, and Covington; and U. S. Highway 220 which extends in a northerly direction through Fincastle, Covington, and Warm Springs. The area is also served by numerous state highways which connect with the main highways and offer ready accessibility to most of the limestone and dolomite deposits.

GEOLOGY

General Statement

The land features, rocks, and soils within the James River district, as well as throughout the Appalachian Valley, are the result of a succession of events through a long period of geologic time. These natural changes are continuing today, but so slowly that they are not generally observable.

The history of the Appalachian Valley began with the subsidence of a narrow belt in the eastern part of North America, extending at least from Newfoundland into Alabama. This gradual subsidence resulted in the formation of a large trough (Appalachian geosyncline) which was gradually flooded many times by interior seas. Streams flowing from neighboring land areas, and to a lesser extent the wind, transported and deposited sediments in this ancient seaway throughout most of the Paleozoic era. The deposits of mud, silt, sand, and gravel were compacted and cemented into stratified or layered shale, sandstone, and conglomerate. The limestones and dolomites were formed from limy materials, in part derived in solution from the bordering lands. Many of the rocks show shallow-water features, such as mud cracks, cross-bedding, and ripple marks; thus it is assumed that at no time during subsidence was the bottom of the interior sea at great depths and at times a part of it was dry land.

A study of the rock record shows that deposition in this geosyncline was not continuous throughout the time assigned to the rock column, nor was the same type of sediment universally distributed. A comparison of two or more separated geologic sections frequently exhibit the fact that certain beds identified in one area may not be represented at another locality. In other instances a shale may grade into a limestone, or a dolomite into a limestone, thus giving rise to change in facies. A thickness of approximately 25,000 feet of sedimentary rocks is estimated for the James River district.

The extremely long period of deposition in the geosynclinal trough was followed toward the end of the Paleozoic era by intense crustal movements which compressed the thick mass of sedimentary rocks and elevated them above sea-level. During this period of orogeny, the rocks were folded, fractured, and faulted. In some areas the rocks were broken into large segments and thrust northwestward one upon the other. One of these major overthrust faults, the Pulaski-Staunton fault, extends for more than two hundred miles in the Appalachian Valley.

Erosion has been active since the rock strata which became the old mountains began to rise above sea-level, having been renewed and intensified from time to time by vertical uplifts of the region. The structure and relative resistance to destructive forces of bedrock play an important role in shaping the landscape. Resistant rocks, such as firm sandstones, form ridges; whereas less resistant rocks, such as limestone and shale, become valleys.

Rock Types

Geologic formations used by stratigraphers within the James River district and the mapped units (Pl. 1) of this report are shown in Table 4. The pre-Martinsburg, post-Beekmantown formations are taken from a recent paper by B. N. and G. A. Cooper (1946); upper Silurian and lower Devonian units after F. M. Swartz (1929, p. 27-75; 1939, p. 29-91); and the remaining part of the column are the names used by Butts (1940). The probable correlation of the newer and older names for the Lower Middle Ordovician is given in Table 5.

Cambrian Dolomite

Shady (Tomstown) dolomite.—The thick succession of Lower Cambrian clastic rocks which crop out mainly on the lower northwestern flanks and spurs of the Blue Ridge is overlain in normal geologic sequence by the Shady dolomite (Pl. 1, unit A), the oldest carbonate formation in the Appalachian Valley of Virginia. This belt of Cambrian dolomite, meeting the specifications of high-magnesium dolomite as defined in this report, crops out at several localities in the vicinity of Natural Bridge Station, Indian Rock, Buchanan, and Lithia (Pl. 1, unit A). Locally, the Shady dolomite is concealed by older rocks along overthrust faults southwest of Natural Bridge Station and, so far as known, is entirely covered by material washed down from the Blue Ridge north of Buena Vista. Notwithstanding this general restricted distribution, there are two active quarries along this belt and several additional potential quarry sites.

The belt of Cambrian dolomite, although not fully displayed in any exposure, has a thickness of approximately 1,200 feet at a locality (Pl. 1, loc. 82) about one-fourth of a mile north of Natural Bridge Station. Other incomplete exposures which were measured commonly show a thickness of from 500 to 700 feet. The rock is medium- to fine-grained, and varies in color from bluish-gray to flesh-colored; the lighter colors predominating in the middle portion of the section near

TABLE 4.—ROCK TYPES IN THE JAMES RIVER DISTRICT WEST OF THE BLUE RIDGE, VIRGINIA

Period	Formation[a]	Rock Character	Mapped Units (Plate 1)
DEVONIAN	Chemung	Shale and sandstone, mostly gray and green; a few reddish layers.	SHALE AND SANDSTONE —H—
	Brallier	Stiff greenish siliceous shale and thin evenly bedded, fine-grained sandstone.	
	Millboro	Black fissile shale; locally contains limestone concretions.	
	Onondaga	Greenish hackly weathering shale; locally cherty.	
	Ridgeley	Thick-bedded, coarse-grained, calcareous sandstone; weathers to friable sandstone.	LIMESTONE AND SANDSTONE —G—
	Licking Creek[b]	Thick- to massively bedded, coarse-grained, gray, locally arenaceous limestone in the upper part and a lower member of cherty, dark-gray, nodular limestone; locally, high-calcium limestone.	
	New Scotland[b]	Dark-gray, fine-grained limestone with variable amounts of white chert in the northern part of the district and light-gray, fine-grained, locally cross-bedded calcareous sandstone (Healing Springs sandstone) to the south.	
	Coeymans[b]	Massively bedded, coarse-grained, mottled gray and pink limestone; locally, high-calcium limestone.	

SILURIAN	Keyser	Fine-grained, dark-gray to light-gray limestone; locally, intercalated gray sandstones (Clifton Forge sandstone).	
	Tonoloway [c]	Laminated, fine-grained, dark-gray to black limestone; weathers shaly.	
	Wills Creek [c]	Chiefly gray sandstone and yellowish shale.	
	Clinton	Massive gray sandstone (Keefer) at top; greenish shale and brownish-red sandstone (Cacapon) in lower part.	SANDSTONE AND SHALE —F—
	Tuscarora	Thick-bedded, light-gray sandstone.	
ORDOVICIAN	Juniata	Chiefly red shale or mudrock and brown to red sandstone; includes a few layers of gray sandstone.	
	Martinsburg	Chiefly calcareous shale which weathers yellowish-brown; includes layers composed largely of very fine quartz sand and thin layers of coarse-grained impure limestone in lower part.	
	Collierstown	Shell limestone with intercalated buff, argillaceous limestone and buff shale; probably equivalent to the Oranda mudrock and siltstone in the northern part of Shenandoah Valley.	LIMESTONE AND SHALE —E—
	Edinburg: Liberty Hall facies	Composed mainly of black limestone and black shale.	
	Lantz Mills facies	Composed mainly of cobbly to nodular, buff weathering limestones.	
	Botetourt member	Brown-weathering granular limestone; not noted west of Great Valley.	

TABLE 4.—ROCK TYPES IN THE JAMES RIVER DISTRICT WEST OF THE BLUE RIDGE, VIRGINIA—Continued

Period	Formation[a]	Rock Character	Mapped Units (Plate 1)
ORDOVICIAN	Lincolnshire	Composed mainly of fine- to medium-grained, dark-gray to black, cherty limestone. Coarse-grained, high-calcium, light-gray limestone (Murat facies) is intercalated in or closely associated with cherty limestones at certain localities; locally, high-calcium limestone.	LIMESTONE —D—
	Whistle Creek	Prevailingly dark bluish to brownish-gray irregularly bedded, very cherty limestone. Identified in the Lexington area locally.	
	New Market	Composed mainly of dove-gray, compact limestone. Two divisions generally recognizable; a lower zone of thin-bedded dove-gray limestone with a few feet of limestone- and dolomite-pebble conglomerate at the base, and an upper zone which is thick-bedded, high-calcium limestone. Locally, the limestones are dark-gray and cherty.	
	Beekmantown	Chiefly thick-bedded, fine- to medium-grained, light- to dark-gray dolomite with minor amounts of light bluish-gray limestone. Several horizons yield masses of gray chert.	DOLOMITE AND LIMESTONE —C—
	Chepultepec	Bluish-gray limestone with a few thin beds of gray dolomite.	

CAMBRIAN	Conococheague	Dark bluish-gray limestone and medium- to dark-gray dolomite; abundant thin wavy siliceous partings and intercalated layers of coarse-grained sandstone. Largely dolomite in the southwestern part of district.	DOLOMITE AND LIMESTONE —B—
	Elbrook	Chiefly thick-bedded to shaly weathering impure dolomite and limestone.	
	Waynesboro	Heterogeneous mixture of red and green shale, fine-grained sandstone and impure dolomite and limestone.	
	Shady-Tomstown	Chiefly fine- to medium-grained, thick-bedded, light- to dark-gray, high-magnesium dolomite.	DOLOMITE —A—
	Basal quartzites	Sandstone, shale, and quartzite.	CLASTIC ROCKS (not mapped)

[a]All formations of the mapped units are not necessarily present at each locality cited in the text.
[b]Helderberg group. [c]Cayuga group.

Natural Bridge Station. All of the sampled units throughout the area contain more than 40 percent magnesium carbonate; the majority about 42 percent; and a few more than 43 percent. Details concerning the thickness, rock character, and chemical composition are given under the discussion, high-magnesium dolomite.

Cambrian Dolomite and Limestone

This mapped unit (Pl. 1, unit B), with an estimated thickness of about 6,000 feet, includes in ascending order the Waynesboro, Elbrook, and Conococheague formations.

Waynesboro (Rome) formation.—The Waynesboro or what is called the Rome formation southwest of Roanoke, Virginia, directly overlies the Cambrian dolomite and crops out mainly in one broad belt in the eastern part of the James River district, extending southwestward through Vesuvius, Buena Vista, and Buchanan. A part of the formation, occurring as faulted slices along the Pulaski-Staunton fault, has been noted also between Eagle Rock and Buchanan, and in the vicinity of Newport in southern Augusta County. Elsewhere within the district erosion has not extended to sufficient depths to expose the Waynesboro. Excellent exposures of parts of the formation may be studied along the Norfolk and Western Railway between Buchanan and Lithia and in the vicinity of Indian Rock, Rocky Point, and Buena Vista. The Waynesboro is extremely heterogeneous in character, being composed of variable proportions of red and green shale, brown fine-grained sandstone, and impure limestone and dolomite. The intercalations of maroon-colored shales and layers of impure dolomite (Pl. 2C) which weather to ochreous rocks are distinctive features for identification. Most of the sampled dolomite layers in the lower part of the Waynesboro contain from about 36 to 39 percent magnesium carbonate and from 7 to 10 percent silica. These layers, although not meeting the requirements for high-magnesium dolomite, are suitable for construction purposes. Although no complete sections of the Waynesboro were observed by the writer, it is probable that the section by Butts (1940, p. 63) in the vicinity of Buchanan which gives a thickness of about 2,000 feet may apply in other parts of the district.

Elbrook formation.—The Elbrook formation, in normal sequence above the Waynesboro, crops out in three main belts; along the southeastern side of the district; east of the Pulaski-Staunton fault in the central part of the valley; and along the North Mountain fault north

of Lexington. The largest area underlain by the Elbrook is between Fincastle and Buchanan in Botetourt County. Like the underlying formations, there are no exposures of the Elbrook in the western part of the district. The Elbrook is composed largely of dolomite with minor amounts of intercalated bluish-gray limestone. Many thick zones within the formation are clayey limestone and dolomite which weather to shaly plates (Pl. 2B). Sampled units of the more massively bedded dolomites generally show from about 37 to 40 percent magnesium carbonate and from 7 to 9 percent silica. One exception was noted in the vicinity of Buffalo Forge (Pl. 1, loc. 112) where 200 feet of dolomite within the upper part of the Elbrook contains 42.5 percent magnesium carbonate. On the basis of detailed measurements along the Chesapeake and Ohio Railway northwest of Buena Vista a thickness of about 2,200 feet is assigned to the Elbrook.

Conococheague limestone.—The Conococheague limestone is exposed on the flanks of the Natural Bridge syncline; west of the Pulaski-Staunton fault north of Lexington; and, in the central and western parts of Fincastle Valley. Three different facies were noted in the James River district: impure limestone with minor amounts of dolomite east of the Pulaski-Staunton fault north of Buchanan; interbedded limestone and dolomite in the northwestern belts; and largely dolomite with minor quantities of limestone in the area between Compton and Eagle Rock. The formation is marked by two distinctive features: thin laminae, containing siliceous material, which stand out as crinkly ribs on weathered surfaces (Pl. 2A) of limestone, and beds of coarse-grained, friable sandstone. The siliceous banded limestones are generally more abundant near the top of the formation. Sampled units of the limestone contain from 71 to 89 percent calcium carbonate; those of dolomite from 33 to 38 percent magnesium carbonate. Silica varies from about 7 to 17 percent. The thickness of the Conococheague southeast of Natural Bridge is approximately 2,100 feet.

Ordovician Dolomite and Limestone

Dolomites and intercalated limestones of Ordovician age crop out in several belts in the eastern part of the James River district and along the crests of the Rich Patch and Warm Springs anticlines west of the Great Valley (Pl. 1, unit C). This mapped unit (Table 4) includes the Chepultepec limestone at the base and the overlying Beekmantown formation.

Chepultepec limestone.—The Chepultepec limestone is one of the best horizons for mapping purposes throughout most of the Valley of Virginia. In this region, it is composed largely of bluish-gray, slightly laminated, fine-grained limestone and minor amounts of thin intercalations of dolomite and magnesian limestone. The maximum thickness of the formation is estimated at 500 feet. Sampled units commonly contain from about 85 to 90 percent calcium carbonate, around 6 percent magnesium carbonate, and from 4 to 6 percent silica. The Chepultepec, for the most part, crops out in narrow valleys bordered by low hills underlain by the more resistant impure rocks of the Conococheague and Beekmantown formations.

Beekmantown formation.—The Beekmantown formation, with an estimated thickness of about 1,500 feet, is composed largely of gray, fine- to medium-grained dolomite. In the eastern belts, limestone perhaps comprises from 10 to 15 percent of the total thickness, whereas only an occasional thin limestone layer was noted in the western portion of the valley. The layers of dolomite are commonly characterized by distinct intersecting furrows on weathered surfaces. Sampled units of dolomite contain from 34 to 39 percent magnesium carbonate and from 5 to 10 percent silica. Chert, although generally not abundant, occurs locally as scattered irregular masses and as distinct beds at several horizons in the formation. The Beekmantown is admirably suited for construction purposes, but does not meet the specifications for high-magnesium dolomite as defined in this bulletin.

Ordovician Limestone

The unit mapped as Ordovician limestone (Pl. 1, unit D) as well as the overlying unit, Ordovician limestone and shale (Pl. 1, unit E), contain stratigraphic problems which have been described in a publication on northern Virginia (Cooper and Cooper, 1946, p. 35-114). This paper indicates that many of the Lower Middle Ordovician rock units of older reports and maps have not been consistently named and, therefore, should be supplanted by new stratigraphic names which facilitate a clearer and more accurate understanding of the geologic events.

A tentative correlation of the new stratigraphic names in Shenandoah Valley (Cooper and Cooper, 1946) with those used on the geologic map of the Appalachian Valley in Virginia (Butts, 1933) are given in Table 5. Since only a few sections were studied west of the

TABLE 5.—TENTATIVE CORRELATION OF THE PRE-MARTINSBURG-POST-BEEKMANTOWN FORMATIONS OF BUTTS WITH THE REVISED CLASSIFICATION OF B. N. AND G. A. COOPER IN SHENANDOAH VALLEY, VIRGINIA

B. N. and G. A. Cooper (1946, p. 71-92)	Butts (1940, p. 95-219)
Martinsburg formation	Martinsburg formation
Collierstown limestone; Oranda formation in central and northern Shenandoah Valley.	Christiania bed of the Chambersburg limestone
Edinburg formation:	
Liberty Hall and Lantz Mills facies	Chambersburg limestone
	Athens formation
Botetourt limestone member	Whitesburg limestone
Lincolnshire limestone	Lenoir[1] and Holston limestones
Whistle Creek limestone	
New Market limestone	Murfreesboro and Mosheim limestones
Beekmantown formation	Beekmantown formation

[1]According to Butts (1933; 1940, p. 438) the Lowville-Moccasin limestone on the northwest side of the Appalachian Valley within the James River district is in contact with the Lenoir limestone and the formations which intervene between the Lenoir and Martinsburg in Shenandoah Valley are absent.

Great Valley, no attempt is made to assign age relationships in that area. The rocks are referred to as Undifferentiated Ordovician Limestones.

New Market limestone.—The name New Market limestone (Cooper and Cooper, 1946, p. 71-74) was proposed for the succession of predominantly dense, fine-grained limestone above the Beekmantown and below the dark-gray, medium-grained, commonly cherty Lincolnshire limestone, or locally as in the Lexington area the Whistle Creek limestone. The New Market limestone is essentially the same as the formation identified by Butts as Mosheim in northern Virginia. At other localities, mainly along the belts northwest of Lexington and Newport, it includes also Butts' Murfreesboro, which is composed of impure limestone and angular fragments of chert and locally intervenes be-

tween the Beekmantown and Mosheim. The New Market limestone is composed largely of thick-bedded, compact to a glassy, bluish-gray to dove-gray limestone. Among distinguishing characteristics are specks of transparent calcite scattered through many of the layers and thin films of chalk-like material on weathered surfaces. The thickness ranges from a few feet in the belts northwest of Lexington to a possible maximum of more than 200 feet in the Highbridge Church-Indian Rock belt. However, the occurrence of chert and other impurities in the lower part of the abnormally thick sections indicates that the full thickness does not meet the specifications of high-calcium limestone. Field studies indicate that this formation, the chief "quarry rock" of the Appalachian Valley, contains at least 100 feet of high-grade limestone at several localities in Warm Springs valley. Sampled units, except where containing chert nodules, generally average about 97 percent calcium carbonate.

The upper members of the unit mapped as Ordovician limestone include, depending upon locality, the Whistle Creek and Lincolnshire limestones.

Whistle Creek limestone.—The Whistle Creek is named (Cooper and Cooper, 1946, p. 74-75) and described as a cherty, dark-bluish to brownish-gray, irregularly bedded limestone which underlies the Lincolnshire limestone in the Lexington area, and succeeds the New Market limestone. The thickness is given as 82 feet at the type locality about 2 miles northwest of Lexington. It comprises the lower part of the Lenoir limestone as previously described and mapped in older reports.

Lincolnshire limestone.—The Lincolnshire limestone (Cooper and Cooper, 1946, p. 75-78) includes those beds above the New Market (Mosheim of Butts) limestone or locally the Whistle Creek and below either the brownish-weathering beds of the Botetourt (Whitesburg of Butts) limestone or below younger beds of the Edinburg formation. The Lincolnshire varies from dark-gray, cherty limestone with minor intercalations of light-gray, coarsely granular limestone to thick units composed chiefly of the coarse-grained, high-calcium limestone. It is essentially the same as Butts' Lenoir limestone in northern Virginia and the Lenoir and overlying Holston limestones recognized by him in the Lexington area. The Holston limestone has subsequently been described as representing not a time-stratigraphic unit, but only a characteristic facies of clastic reefy high-calcium limestone within the Lincolnshire formation.

The maximum thickness of the Lincolnshire or its equivalent Lenoir and Holston limestones is about 200 feet in the vicinity of Murat southwest of Lexington. Sampled units of this coarsely granular limestone, or *Murat limestone facies* of the Lincolnshire, along the belt between Lexington and Murat contain from 97 to 98 percent calcium carbonate and represent some of the largest limestone reserves in the James River district.

Ordovician Limestone and Shale

The unit mapped in this report (Pl. 1, unit E) as Ordovician limestone and shale includes the Edinburg formation and the Collierstown limestone. No commercial thicknesses of high-calcium limestone were observed in this unit within the James River district.

Edinburg formation.—The name Edinburg formation (Cooper and Cooper, 1946, p. 78-86) has been proposed for a relatively thick section of impure limestones and shales which extends from the top of the Lincolnshire to near the base of the Martinsburg, being separated from the Martinsburg by the Collierstown limestone. The Edinburg is equivalent to the beds identified by Butts as Whitesburg, Athens, and Chambersburg limestones in the Great Valley and the Lowville limestone in Warm Springs valley where the other formations mentioned are absent. The Edinburg consists of two facies—*Liberty Hall* and *Lantz Mills.* The Liberty Hall facies is composed mainly of black limestone and black shale; the Lantz Mills facies, cobbly to nodular, buff-weathering limestone. Near the base of the Edinburg, locally in the James River district, are a few feet of rusty-weathering granular limestone of *Whitesburg* lithology which has been renamed (Cooper and Cooper, 1946, p. 80) the *Botetourt* limestone. The thickness of the unit, Ordovician limestone and shale, in this area varies from about 500 to 1,000 feet.

Collierstown limestone.—The Collierstown limestone is a zone of dark-colored, impure limestone and buff shales, generally less than 75 feet thick (Cooper and Cooper, 1946, p. 90).

Ordovician and Silurian Sandstone and Shale

Noncarbonate rocks conspicuously displayed in the Valley and Ridge section of the James River district include about 3,000 feet of sandstone and shale. According to the geologic map of the Appalachian Valley in Virginia the formations comprising the unit mapped

as Ordovician and Silurian sandstone and shale (Pl. 1, unit F) include, in ascending order, the Martinsburg shale, Juniata formation, Tuscarora (Clinch) sandstone, and Clinton formation. A brief statement of the rock character of each formation listed above is given in Table 4, compiled, in part, from a comprehensive report on geology of the Appalachian Valley by Charles Butts (1940).

Upper Silurian and Lower Devonian Limestone and Sandstone

This unit (Pl. 1, unit G) includes the Ridgeley sandstone, Keyser limestone, and several limestone and sandstone formations comprising the Helderberg and Cayuga groups. The upper member of the Cayuga group (Tonoloway limestone), the Keyser limestone, and the Coeymans, New Scotland, and Licking Creek limestones comprising the Helderberg group are the carbonate members which were measured and sampled at a few localities within the James River district. Correlation of the Keyser limestone and Helderberg group from Monterey to Prices Bluff is given by F. M. Swartz (1929, fig. 17). The calcareous rocks of the Helderberg group are overlain by a coarse-grained, friable sandstone identified as the Ridgeley formation. In the vicinity of Lowmoor and at Island Ford in Alleghany County the thickness is estimated to be about 25 feet. In the absence of detailed faunal studies the boundaries within the Helderberg group shown in the various geologic sections should be considered tentative.

Tonoloway limestone.—The Tonoloway limestone is a thin-bedded or laminated, fine-grained, dark-gray to black, impure limestone. No completely exposed sections of the Tonoloway were noted in the James River district, but to the north in the vicinity of Monterey, Highland County, the thickness is reported (Butts, 1940, p. 263) to be about 450 feet.

Keyser limestone.—According to F. M. Swartz (1929, p. 51, 57), the Keyser limestone shows notable changes within the James River district. The Big Mountain shale member separating the lower limestone member from the upper limestone of the Keyser is maintained as far south as Bolar, Virginia, and then tongues out, giving place to sandstone. Tongues of sandstone are also introduced into the limestone members of the Keyser, beginning in the sections west of Warm Springs and Hot Springs. These sandstones (Clifton Forge member

of the Keyser) thicken in a southwesterly direction and at Clifton Forge have an aggregate thickness of 66 feet.

The carbonate part of the Keyser consists of dark-gray, fine- to medium-grained, in part nodular weathering limestone. The thickness determined at several localities in the central part of the James River district ranges from about 100 to 175 feet.

Coeymans limestone.—The Coeymans limestone, commonly referred to as a marble, is a coarse-grained, gray to pink crinoidal limestone. Usually the boundary with the underlying Keyser is sharp, whereas the upper boundary may be transitional where massive crystalline limestone is developed in the lower part of the New Scotland (Geologic Sections 48 and 49). The thickness varies from about 10 feet at Island Ford southeast of Covington to a possible maximum of about 50 feet in the vicinity of Callaghan. At Dunlap Beach southeast of Callaghan the full thickness of about 45 feet shows 96.4 percent calcium carbonate, 1 percent magnesium carbonate, and less than 1 percent silica.

New Scotland limestone.—The New Scotland limestone in the vicinity of Monterey is dark-gray, fine-grained, cherty limestone. South of Monterey, the New Scotland is described (Swartz, 1929, p. 41) as becoming arenaceous in its lower half, as at Bolar and Dry Run, and finally the calcareous sandstone (in part arenaceous limestone) entirely replaces the cherty limestone, forming the Healing Springs sandstone member.

Licking Creek limestone.—Studies by Swartz (1939, p. 69) show that the rocks, originally described as the Becraft limestone, lying between the New Scotland limestone or Healing Springs sandstone and the overlying Ridgeley sandstone of the Oriskany group in the Clifton Forge region should be designated the Licking Creek limestone. Lesure (1957, p. 49) describes the Licking Creek limestone in the Clifton Forge area as composed of two distinct lithologies segregated to form an upper member of light- to medium-gray, arenaceous coarse-grained limestone and a lower member of medium- to dark-gray, cherty fine-grained limestone (Pl. 4B). At certain localities within the James River district the upper member of the Licking Creek limestone shows a thickness of about 50 feet and contains from about 92 to 95 percent calcium carbonate. Other localities show an abundance of quartz sand and white chert.

Devonian Shale and Sandstone

Broad belts of Devonian shale and sandstone (Pl. 1, unit H) in the western part of the James River district are well displayed in the Elliott Knob syncline north of Rockbridge Alum Springs, the McClung syncline between Clifton Forge and Eagle Rock, the Monterey syncline west of Warm Springs and Covington, and along the eastern flanks of Allegheny Mountain at the Virginia-West Virginia line. These clastic rocks, with an aggregate thickness of about 5,000 feet, are shown separately on the Geologic Map of the Appalachian Valley in Virginia as the Onondaga, Millboro, Brallier, and Chemung formations.

Mississippian Shale and Sandstone

Small belts of Price shale and sandstone occur west of the Pulaski-Staunton fault along the Botetourt-Craig County line.

STRUCTURE

The sedimentary rocks in the James River district are now generally inclined at angles to the almost horizontal position in which they were deposited. The present attitude and distribution of these rocks indicate that they have been bent into upfolds (Pl. 7C), or anticlines, and downfolds, or synclines, and subsequently deeply eroded. Most of the axes of these folds and the truncated edges of the strata which crop out along the limbs of the structures are approximately parallel and trend northeastward. In many places the normal geologic sequence of formation is modified by great fractures (faults) along which the strata are displaced. A few of the larger structures in the district are briefly described below.

One of the major structures in this district is the Massanutten Mountain syncline, which extends from the vicinity of Buchanan, Botetourt County, on the southwest, northeastward into Berkeley County, West Virginia. The main area of the syncline, occupied by Martinsburg shale and sandstone, terminates in the vicinity of Greenville, Augusta County, but in a broad sense the syncline includes also the carbonate rocks which crop out on the flanks of the structure in the vicinity of Natural Bridge and east of the Pulaski-Staunton fault as far southwestward as the Rockbridge-Botetourt County line. The formations, chiefly limestones and dolomites, of the Massanutten Mountain syncline are bounded on the northwest side by the Pulaski-Staunton fault, a major overthrust which extends northeast-southwest far beyond the limits of the area described in this paper. Locally, along the trace of this fault there are faulted slices and diverging branches which constitute a faulted zone.

In the broad area referred to as Fincastle Valley there is an irregularly shaped structural basin with Ordovician limestone and shale occupying the medial part of the fold. Like the main valley to the northeast this area is limited on the northwest side by an overthrust fault.

The western part of the Great Valley, between the Pulaski-Staunton fault and the general position of Little North Mountain or other ridges bearing the same relation to the valley on the northwest, is characterized by a number of small plunging folds and associated faults. Some of the more prominent of these structures are the Short Hills syncline, Rapps Mill anticline, and several alternating anticlines and synclines northwest of Lexington. Another major overthrust in

the Valley of Virginia is the North Mountain fault which enters the James River district north of Newport and extends thence southwestward to the vicinity of the Rockbridge-Botetourt County line.

The principal geologic structures northwest of the Great Valley, including more than two-thirds of the total area of the James River district, consist of a number of relatively long, narrow overlapping folds (Pl. 1). Except in the Rich Patch and Warm Springs anticlines, erosion has not penetrated deep enough to expose rocks older than Silurian sandstones and shales.

For a detailed discussion of the geologic structure in central and western Virginia the reader is referred to selected references cited in the bibliography of this report.

DEVELOPMENT POSSIBILITIES

General Statement

No pretense is made in the following discussion to recommend any particular locality as meeting all the requirements for commercial development. Any such statement would necessitate more detailed geologic study, actual testing by core-drilling, and a careful consideration of numerous economic and technological factors. It is the purpose of this report to outline the distribution of the various types of carbonate rocks and to give for selected localities an interpretation of the thickness, structure, lithology, and chemical composition. In addition, the physical properties of selected samples are summarized in Table 8.

Suggested use of this report is as follows:

1) Consult Table 7 which lists the chemical composition of the sampled units and note which meet the specifications required;
2) Examine the geologic map (Pl. I) for the general location and distribution of the rocks described and analyzed;
3) Study the particular geologic section in the text which gives the general geologic sequence, lithology, and thickness of the rocks.

High-Calcium Limestone

Highbridge Church-Indian Rock belt.—This narrow belt of Ordovician limestone, locally containing thick deposits of high-calcium limestone, extends from a point about one mile northeast of Highbridge Church southwestward to the vicinity of Indian Rock, a distance of six miles. The rocks comprising the northeastern end of the belt are partly exposed along U. S. Highway 11 northeast of the Rockbridge-Botetourt County line; whereas, in Botetourt County, to the southwest they crop out about three-fourths of a mile east of the highway. Some of the best exposed sections of rocks are in the valley of Roaring Run and along State Roads 610 and 622 which cross the area in a southeasterly direction.

James River, a meandering stream flowing northeastward along the western foothills of the Blue Ridge, is about half a mile east of the Ordovician limestone belt at Rocky Point (Pl. 1). This river at an altitude of 750 feet along the Rockbridge-Botetourt County line is entrenched several hundred feet below the general level of the dis-

sected valley surface on the northwest. Most of the higher points of the valley section in this area range in altitude from about 1,200 to 1,400 feet. Because of this rather deep entrenchment of James River and its tributaries none of the quarries which have operated on this belt of Ordovician limestone have been troubled with groundwater.

The Highbridge Church-Indian Rock belt of Ordovician limestone is well situated with regard to rail transportation. The James River Division of the Chesapeake and Ohio Railway closely parallels James River on the west side; whereas, the Shenandoah Division of the Norfolk and Western Railway is on the east side.

Geologically, this belt of Ordovician limestone is a part of a faulted slice along the Pulaski-Staunton fault, a major overthrust in the Valley of Virginia. The units mapped (Pl. 1) in this faulted slice, from west to east, include Cambrian dolomite and limestone; Ordovician dolomite and limestone; Ordovician limestone; and, Ordovician limestone and shale. Only the unit mapped as Ordovician limestone contains thick deposits of high-calcium limestone.

Geologic Sections 1 to 5, beginning with number one near the Rockbridge-Botetourt County line (Pl. 1, loc. 1), give the character and thickness of the rock comprising the Highbridge Church-Indian Rock belt of Ordovician limestone.

GEOLOGIC SECTION 1.—NEAR ROCKBRIDGE-BOTETOURT COUNTY LINE ABOUT 500 FEET SOUTHEAST OF U.S. HIGHWAY 11, BOTETOURT COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone and shale	
Edinburg formation (lower part)	
9. Botetourt limestone member, dark-gray, coarse-grained, nodular, rusty-weathering	10-15
Ordovician limestone: strike N. 45°-65° E.; dip 50° SE.	
Lincolnshire limestone (205 feet)	
8. Murat limestone facies, light-gray, chiefly coarse-grained	60-75
7. Covered interval	75
6. Limestone, dark-gray, fine-grained, sparsely cherty, partly covered	35
5. Limestone, light-gray, fine-grained to compact	5
4. Murat limestone facies, light-gray, coarse-grained	10
3. Limestone, dark-gray, fine-grained	5
New Market limestone	
2. Limestone, light-gray, compact	60
Ordovician dolomite and limestone	
Beekmantown dolomite (upper part)	
1. Dolomite, gray, fine-grained	150

Although no samples were collected for chemical analyses here, it is thought that units 2, 4, and 8 would meet the requirements of high-calcium limestone as defined in this report. Generally speaking, all of the light-colored, coarse-grained limestones (Murat facies of the Lincolnshire) and the light-gray, compact limestone (New Market limestone) in the James River district, which are free of chert nodules and clayey partings, contain more than 95 percent calcium carbonate.

The Ordovician limestone belt continues southwestward to State Road 610 along Roaring Run where the units shown in the following composite section (Pl. 1, loc. 2) were measured.

GEOLOGIC SECTION 2.—ALONG STATE ROAD 610 AND IN THE HILL ABOUT 100 YARDS NORTHEAST OF ROARING RUN ABOUT 1½ MILES NORTHEAST OF ROCKY POINT, BOTETOURT COUNTY, VIRGINIA

	Thickness Feet
Cambrian dolomite and limestone thrust upon Ordovician limestone and shale along the Pulaski-Staunton fault.	
Ordovician limestone and shale	
Edinburg formation (lower part)	
8. Limestone and shale, crumpled, brecciated; probably includes about 10 feet of brecciated Botetourt limestone at the base	40
Ordovician limestone: strike N. 40°-45° E., dip 35°-50° SE.	
Lincolnshire limestone (191 feet)	
7. Murat limestone facies, mainly light-gray, coarse-grained, sheared; contains beds mottled with dark-colored fragments of fossils; thickness estimated because of uncertain structure; $CaCO_3$, 97.75; $MgCO_3$, 1.00; SiO_2, 0.33; Al_2O_3, 0.36; Fe_2O_3, 0.44; total, 99.88	144±
6. Limestone, gray, medium-grained, impure	14
5. Limestone, dark-gray, shaly, cherty; contains a few reddish streaks	13
4. Murat limestone facies, dark- to medium-gray, coarse-grained	20
New Market limestone (82+ feet)	
3. Limestone, light-gray, compact- to fine-grained; sheared in lower part	72
Analysis of units 3 and 4, sampled thickness 92 feet; $CaCO_3$, 96.71; $MgCO_3$, 1.33; SiO_2, 0.74; Al_2O_3, 0.31; Fe_2O_3, 0.50; total 99.59. A separate analysis of a hand specimen of unit 3 shows 97.40 percent of calcium carbonate.	
2. Covered interval; takes to top of dolomite	10+

Ordovician dolomite and limestone
Beekmantown dolomite (upper part)
1. Dolomite, gray, fine-grained, cherty, $CaCO_3$, 53.49; $MgCO_3$, 35.90; SiO_2, 7.28; Al_2O_3, 2.52; Fe_2O_3, 0.80; total, 99.99..... 307

Between localities 2 and 3, a distance of three-fourths of a mile, the lower or New Market limestone part of the Ordovician limestone belt is displayed along Roaring Run and in the adjacent steep valley slopes on the northwest. Field studies indicate that this zone of high-calcium limestone thickens in a southwesterly direction.

The quarry of the Liberty Limestone Corporation, when visited in 1956, had a length of about 800 feet and a width estimated to be 400 feet. The depth varied from about 60 feet along the northwest side to a maximum of 100 feet at the southwestern end. The thickness and character of the rocks which crop out at the southwestern end of the quarry (Pl. 1, loc. 3) are shown in the following section.

GEOLOGIC SECTION 3.—SOUTHWESTERN END OF LIBERTY LIMESTONE CORPORATION QUARRY ABOUT A MILE NORTH OF ROCKY POINT, BOTETOURT COUNTY, VIRGINIA

	Thickness Feet
Cambrian dolomite and limestone thrust upon Ordovician limestone and shale along the Pulaski-Staunton fault.	
Ordovician limestone and shale	
Edinburg formation (lower 68 feet)	
16. Shale, black; weathers yellowish-brown; thickness estimated	60
15. Botetourt limestone member, dark-gray, medium-grained, rusty-weathering; lower boundary uncertain.....	8
Ordovician limestone; strike N. 43° E; dip 47° SE.	
Lincolnshire limestone (206 feet)	
14. Limestone, dark-gray, medium-grained, nodular.....	30
13. Murat limestone facies, light-gray, coarse-grained.....	65
12. Limestone, gray to dark-gray, medium-grained.....	13
11. Limestone, dark-gray, medium-grained; contains shaly partings	3
10. Murat limestone facies, light-gray, medium- to coarse-grained	50
9. Limestone, dark-gray, fine-grained.....	15
8. Limestone, dark-gray, cobbly, cherty.....	5
7. Limestone, dark- to medium-gray, medium-grained.....	25
New Market limestone (150± feet)	
6. Limestone, dove-gray, compact.....	78
5. Limestone, black, compact; contains thin layer of shale.....	3
4. Limestone, dove-gray, compact.....	9
3. Limestone, dark-gray, fine-grained.....	5

2. Limestone, black, compact; forms dip slope on western side of quarry 5
1. Covered interval; first exposure of dolomite is about 50 feet west of quarry..... 50

Ordovician dolomite and limestone

The Liberty Limestone Corporation quarry is along Roaring Run at a locality where the stream cuts southeastward across the limestone belt. The altitude in the lowest part of the quarry is approximately 1,000 feet, whereas the prominent hill between the quarry and State Road 622 on the southwest is 1,300 feet. Since the belt of Ordovician limestone, striking N. 43° E., and dipping 47° SE., crops out on the surface across this high ground it is probable that the quarry could be extended in a southwesterly direction for approximately one-fourth of a mile.

One of the best exposed sections of the Highbridge Church-Indian Rock belt of Ordovician limestone is along and in the low ridge northeast of State Road 622 about midway between U. S. Highway 11 and Rocky Point. The structure appears to be regular along a traverse beginning at the Beekmantown-New Market boundary and extending in a southeasterly direction to the western edge of the inactive quarry (Pl. 1, loc. 4) along State Road 622. Farther east, in the direction of the Pulaski-Staunton fault, the section is complicated by folding and shearing. For example, dark-gray, nodular, cherty limestone, tentatively identified as the upper part of the Lincolnshire and the Botetourt limestone member of the Edinburg, crop out east and west of the quarry. These rocks are repeated again along State Road 622 by a small anticline which exposes a part of the underlying Murat facies of the Lincolnshire limestone. The traverse distance across the strike of the Murat limestone at this locality is about 150 feet.

The following section, beginning with the impure limestone along the eastern side of the inactive quarry, was compiled from exposures along and north of State Road 622.

GEOLOGIC SECTION 4.—ALONG AND NORTH OF STATE ROAD 622 ABOUT HALF A MILE NORTHWEST OF ROCKY POINT, BOTETOURT COUNTY, VIRGINIA

Thickness
Feet

Ordovician limestone: strike N. 10°-35° E; dip 35°-55° SE.
Lincolnshire limestone (units 7-12, 217 feet)
14. Limestone, dark-gray, nodular, cherty..... 10±

13. Murat limestone facies, light-gray, coarse- to medium-grained; structure uncertain, exposed in roadside quarry; $CaCO_3$, 97.62; $MgCO_3$, 0.76; SiO_2, 0.39; Al_2O_3, 0.47; Fe_2O_3, 0.24; total, 99.48	80
Note: Section continues from west side of quarry with rock similar (?) to unit 14 at top of Lincolnshire.	
12. Limestone, dark-gray, nodular, cherty; thickness estimated	10±
11. Murat-limestone facies light-gray, coarse- to medium-grained	65
10. Limestone, medium-gray, slightly cobbly weathering	22
9. Murat limestone facies, light-gray, medium- to coarse-grained	65
8. Limestone, dark-gray, fine-grained, cobbly, cherty	30
7. Murat limestone facies, gray, medium- to coarse-grained; $CaCO_3$, 98.66; $MgCO_3$, 0.62; SiO_2, 0.07; Al_2O_3, 0.35; Fe_2O_3, 0.22; total, 99.92	25
New Market limestone (225 feet)	
6. Limestone, light- to dark-gray, compact; $CaCO_3$, 96.14; $MgCO_3$, 1.45; SiO_2, 0.99; Al_2O_3, 0.43; Fe_2O_3, 0.32; total, 99.33	85
5. Limestone, dark-gray, fine-grained, cherty	15
4. Limestone, dove-gray, compact, massively bedded	18
3. Limestone, dark-gray, compact, cherty	7
2. Largely covered; few exposures of impure compact limestone; thickness uncertain	100+
Ordovician dolomite and limestone	
Beekmantown dolomite (upper part)	
1. Dolomite, shaly, ash-gray	6

Since the repetition of the Murat facies would add to the reserves of high-calcium limestone, it is recommended that more detailed study, including core drilling, be done at this locality to determine accurately the extent of the minor structures and thicknesses of the units cited.

The Ordovician limestone belt, although partly covered, extends from State Road 622 southwestward for about 2 miles to a locality near State Road 614 where it is concealed by older rocks along the Pulaski-Staunton fault. Limestones formerly quarried along this belt were hauled by a spur-line railroad to kilns at Indian Rock. Some of these high-calcium limestones are well displayed along the eastern slopes of a narrow valley tributary to Rock Run. The character and thickness of the rocks which are fully exposed in an inactive quarry (Pl. 1, loc. 5) located about midway between State Roads 614 and 622 are given in the following section.

GEOLOGIC SECTION 5.—INACTIVE QUARRY THREE-FOURTHS OF A MILE SOUTHWEST OF STATE ROAD 622 AND 1¼ MILES NORTHEAST OF INDIAN ROCK, BOTETOURT COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone: strike N. 50° E.; dip 45° SE.	
Lincolnshire limestone (156+ feet)	
6. Murat limestone facies, light-gray, coarse-grained; covered at the top	120
5. Limestone, dark-gray, nodular, clayey	18
4. Murat limestone facies, light-gray, coarse-grained	18
New Market limestone (195+ feet)	
3. Limestone, light-gray, compact	73
2. Limestone, light-gray, granular; contains 4-foot bed of fine-grained, nodular limestone near base	33
1. Limestone, light- to dark-gray, compact; base not exposed. Analysis of units 1-4, sampled thickness 213 feet; $CaCO_3$, 97.65; $MgCO_3$, 1.35; SiO_2, 0.30; Al_2O_3, 0.48; Fe_2O_3, 0.14; total, 99.92	89
Ordovician dolomite and limestone	

Timber Ridge-Murat belt.—The Timber Ridge-Murat belt of Ordovician limestone extends from the Pulaski-Staunton fault east of Timber Ridge southwestward to a locality about one mile southwest of Murat, where the rocks wrap around the end of a southwesterly pitching anticline (Pl. 1). This belt, locally containing thick deposits of high-calcium limestone, is crossed by U. S. Highway 60 northwest of Lexington, State Highway 251 at Murat, and by several secondary roads. A branch line of the Chesapeake and Ohio Railway which ends at Lexington is the nearest shipping point.

Field studies indicate that this belt of Ordovician limestone, due to gentle folding and low dips, crops out in a relatively broad area where crossed by Whistle Creek and Maury River west of Lexington; whereas to the southwest the rocks are confined to a narrower belt because of more regular and steeper dips. None of the sections measured near the northeastern end of the belt contain thick occurrences of high-calcium limestone, although the total thickness of the mapped unit is perhaps greater than in the central or southwestern parts of the area. Generally speaking, the coarsely granular Murat facies of the Lincolnshire limestone in the James River district is not persistent over wide areas and commonly shows marked variations in thickness within distances of a few hundred feet along the strike. The lower part of the Ordovician limestone belt, known as the New Market limestone

or "Mosheim" limestone, is generally thin in this area. However, in Shenandoah Valley to the northeast, it is the chief "quarry rock."

The most northeasterly exposure of the Ordovician limestone belt is about a mile north of State Road 716 and about half a mile east of Timber Ridge (Pl. 1, loc. 6). At this locality, there is about 20 feet of sheared, light-gray, compact New Market limestone, underlain by Beekmantown dolomite and closely overlain by about 100 feet of granular, dark-gray, mostly impure Lincolnshire and Whistle Creek limestone. It is thought that only about 13 feet of coarse-grained limestone, occurring near the base of the Lincolnshire, would meet the specifications of high-calcium limestone. The upper part of the exposed section is within 100 feet of Cambrian dolomite and limestone along the Pulaski-Staunton fault. A description of a full sequence of the Ordovician limestones about 1 mile southwest of locality 6 is given in the following section (Pl. 1, loc. 7).

GEOLOGIC SECTION 6.—ALONG STATE ROAD 717 ABOUT ONE-FOURTH OF A MILE NORTHWEST OF U. S. HIGHWAY 11 AND 1 MILE SOUTHWEST OF TIMBER RIDGE, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone: strike N. 58° E.; dip 30° SE.	
Lincolnshire and Whistle Creek[1] limestones (202 feet)	
7. Covered interval; abundant chert float	18
6. Limestone, dark-gray, medium-grained, cherty	29
5. Murat limestone facies, gray, coarse-grained	17
4. Limestone, dark-gray, medium-grained, nodular	101
3. Murat limestone facies, dark bluish-gray, coarse-grained	21
2. Limestone, dark-gray, impure, sparsely cherty	16
New Market limestone	
1. Limestone, bluish-gray, fine-grained, sheared, impure	24
Ordovician dolomite and limestone	

Although no samples for chemical analyses were collected at locality 7, it is reasonably certain that only units 3 and 5 in the above section, with an aggregate thickness of 38 feet, are high-calcium limestone. The general southwestward trend of the Ordovician limestone belt between localities 7 and 8 is modified by gentle folding. A small anticline and syncline, both pitching southwestward, are displayed

[1] Although the Timber Ridge-Murat belt west of Lexington is the type area of the Whistle Creek limestone, no attempt is made in this paper to distinguish it from the overlying Lincolnshire. It may be assumed that the beds of cherty limestone overlying the New Market are Whistle Creek, but without detailed faunal studies the upper boundary of the unit would be questionable.

along State Road 717 about half a mile northwest of U. S. Highway 11. The character and thickness of the rocks which are partially exposed at locality 8 are given in the following section.

GEOLOGIC SECTION 7.—ALONG STATE ROAD 728 ABOUT THREE-FOURTHS OF A MILE NORTHWEST OF THE JUNCTION OF STATE ROAD 645 AND 5 MILES NORTHEAST OF LEXINGTON, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone and shale	
Edinburg formation (lower part)	
8. Botetourt limestone member, dark-gray, medium-grained, rusty weathering	30
Ordovician limestone: strike N. 57° E.; dip 20°-30° SE.	
Lincolnshire and Whistle Creek limestones (333 feet)	
7. Covered interval; underpass of abandoned railroad	110
6. Limestone, dark-gray, fine- to medium-grained, cherty	58
5. Covered interval; abundant chert float	30
4. Murat limestone facies, light-gray, coarse-grained	10
3. Limestone, dark-gray, cherty; partly covered	125
New Market limestone (32 feet)	
2. Limestone, fine-grained, impure, sheared	29
1. Limestone, dove-gray, compact	3
Ordovician dolomite and limestone	

The thickness assigned to covered or partly covered intervals in the above section should be considered only as estimates, since these figures are based upon an assumed average dip of 20 degrees southeast. It is interesting to note that none of the exposed limestones, except unit 4, appear to be of good quality, thus these observations agree closely with other descriptions along the belt of Ordovician limestone to the northeast, Southwestward from locality 8 to the vicinity of Maury River at Limekiln Bridge, a distance of 3 miles, the belt of Ordovician limestone is largely covered. Beginning with the first exposures between Maury River and State Highway 39 and extending southwestward to the vicinity of Murat, high-calcium limestone comprises a large part of the mapped Timber Ridge-Murat belt and there are many exposed sections for detailed study. In some of the following descriptions only that part of the Ordovician limestone belt, which contains high-calcium limestone is shown in the geologic sections. Some of the best exposures of the Murat facies of the Lincolnshire in the Lexington area are along Maury River (Pl. 1, loc. 9) in the vicinity of Limekiln Bridge.

GEOLOGIC SECTION 8.—ALONG STATE ROAD 631 JUST SOUTHWEST OF LIMEKILN BRIDGE AND ABOUT 2 MILES NORTH OF LEXINGTON, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone: strike N. 70° E.; dip 15° SW.	
Lincolnshire and Whistle Creek limestones (upper 147 feet)	
4. Limestone, dark-gray, nodular, cherty; covered at top....	10+
3. Murat limestone facies, light-gray, medium- to coarse-grained; $CaCO_3$, 97.49; $MgCO_3$, 0.85; SiO_2, 1.28; Al_2O_3, 0.20; Fe_2O_3, 0.16; P_2O_5, 0.063; total, 100.04.....	32
2. Murat limestone facies, light- to bluish-gray; chiefly medium-grained; few covered intervals; $CaCO_3$, 97.29; $MgCO_3$, 1.06; SiO_2, 1.46; Al_2O_3, 0.06; Fe_2O_3, 0.08; P_2O_5, 0.098; total, 100.04	65
1. Limestone, light- to bluish-gray; intercalations of compact and clastic beds; takes to end of bridge.....	40

The same units of coarse- to medium-grained limestone as shown in the above section are exposed in the bluff, approximately 100 feet high, along Maury River from the north end of the bridge southwestward to the mouth of Whistle Creek, a distance of approximately one-fourth of a mile. Additional exposures of high-calcium limestone in this general area are along State Road 664 and in the bluff of Maury River east of Limekiln Bridge.

The Ordovician limestone belt (Pl. 1, loc. 10) is well displayed along State Road 664 for a distance of one-half mile northwest of its junction with State Road 631. No attempt was made to determine thickness of the beds in the upper part of the section, since the strike and dip change rapidly as the axis of the local syncline is approached.

The lower part of the section includes about 72 feet of New Market limestone with clastic chert fragments in the basal beds. The overlying Lincolnshire and Whistle Creek limestones begin with about 130 feet of dark-gray, granular limestone with thin intercalations of shale near the base and grades upward into the typical Murat limestone facies which comprises the main part of the traverse to the vicinity of Limekiln Bridge.

The general area of Limekiln Bridge is recommended for detailed study and core drilling. Such work is indispensible in proving any site, since variable thicknesses of overburden and underground solution cavities, often filled with clayey materials, are commonly found in limestone regions. It is also important to study carefully the specifications required of the rock for specific chemical uses. For example, the relatively high content of phosphorus pentoxide shown by the

analyses in Geologic Section 8 may be objectionable for certain chemical uses.

The Ordovician limestone belt, due to gentle folding, is largely exposed along Whistle Creek for approximately three-fourths of a mile west of Maury River. The character and thickness of the high-calcium limestones along Whistle Creek near the junction of State Roads 665 and 669 (Pl. 1, loc. 11) are given in the following composite section.

GEOLOGIC SECTION 9.—ALONG WHISTLE CREEK NEAR THE INTERSECTION OF STATE ROADS 665 AND 669 ABOUT ONE-FOURTH OF A MILE NORTH OF U. S. HIGHWAY 60 AND 2 MILES NORTHWEST OF LEXINGTON, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone: strike N. 50° E.; dip 15° SE.	
Lincolnshire and Whistle Creek limestones (327 feet)	
11. Limestone, dark-gray, nodular, sparsely cherty; few covered intervals	70
10. Murat limestone facies, light-gray, coarse-grained; bedding indistinct; $CaCO_3$, 98.08; $MgCO_3$, 0.79; SiO_2, 0.84; Al_2O_3, 0.24; Fe_2O_3, 0.16; P_2O_5, 0.065; total, 100.17	70
9. Limestone, dark bluish-gray, shaly, nodular; $CaCO_3$, 92.72; $MgCO_3$, 1.27; SiO_2, 5.04; Al_2O_3, 0.60; Fe_2O_3, 0.40; total, 100.03	7
8. Murat limestone facies, light-gray, coarse-grained; $CaCO_3$, 97.29; $MgCO_3$, 0.76; SiO_2, 1.32; Al_2O_3, 0.44; Fe_2O_3, 0.16; P_2O_5, 0.066; total, 100.03	85
7. Limestone, dark bluish-gray, cobbly weathering	5
6. Limestone, medium bluish-gray, medium-grained	25
5. Limestone, dark bluish-gray, medium-grained, irregularly bedded	18
Analysis of units 5-7, sampled thickness 48 feet; $CaCO_3$, 96.49; $MgCO_3$, 1.06; SiO_2, 1.52; Al_2O_3, 0.40; Fe_2O_3, 0.12; total, 99.59	
4. Limestone, dark-gray, fine-grained, nodular	30
3. Limestone, dark-gray, sparsely cherty	8
2. Limestone, bluish-gray, thin-bedded, impure	9
New Market limestone	
1. Limestone, bluish-gray, fine-grained; contains detrital chert	2±
Ordovician dolomite and limestone	

In the above section units 1-4 were measured along Whistle Creek at a locality about 500 feet east of U. S. Highway 60. These beds do not contain high-calcium limestone. It is notable, however, that the upper part of the section (units 8 and 10) contains about 150 feet of limestone showing more than 97 percent calcium carbonate.

The following section (Pl. 1, loc. 12) although not sampled, is well displayed along the northeast side of Whistle Creek.

GEOLOGIC SECTION 10.—ALONG THE NORTHEAST SIDE OF WHISTLE CREEK ABOUT 200 YARDS EAST OF THE INTERSECTION OF STATE ROAD 665 AND 669 AND 2 MILES NORTHWEST OF LEXINGTON, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone: strike N. 45° E.; dip 15°-25° SE.	
Lincolnshire and Whistle Creek limestones (252 feet)	
8. Murat limestone facies, light-gray, medium-grained, thick-bedded; covered at the top	100
7. Limestone, dark-gray, cobbly	10
6. Murat limestone facies, light-gray, medium-grained, massively bedded	35
5. Limestone, dark-gray, medium-grained, cobbly weathering	30
4. Limestone, dark-gray, nodular weathering	30
3. Limestone, dark-gray, nodular, sparsely cherty	32
2. Limestone, dark-gray, fine-grained, cherty	15
New Market limestone	
1. Limestone, dove-gray, compact; contact appears to be an erosional surface on the underlying dolomite	10-20
Ordovician dolomite and limestone	

The thickness and purity of the New Market limestone varies widely along the Timber Ridge-Murat belt. For example, along State Road 631 about one-fourth of a mile northeast of Limekiln Bridge, the Beekmantown dolomite is closely overlain by the Lincolnshire cherty limestone; whereas about one-fourth of a mile to the west along State Road 664 the thickness of the New Market is estimated to be about 70 feet. Variations in thickness, ranging from about 2 to 30 feet, are to be noted along Whistle Creek from U. S. Highway 60 to locality 12, a distance of not more than 2,000 feet. Field evidence suggests that these variations in thickness are due to an irregular Beekmantown surface upon which the New Market was deposited. At certain localities the New Market is very cherty; whereas, other sections show it to be high-calcium limestone. The thickness and composition of the New Market limestone along U. S. Highway 60 just east of the bridge over Whistle Creek (Pl. 1, loc. 13) is given in the following section.

GEOLOGIC SECTION 11.—ALONG U. S. HIGHWAY 60 ABOUT 2 MILES NORTHWEST OF LEXINGTON, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone (lower part)	
New Market limestone (31 feet): strike N. 55° E.; dip 18° SE.	
3. Limestone, light-gray, fine-grained, thick-bedded.....	16
2. Limestone, light bluish-gray, medium-bedded, sparsely cherty	2
1. Limestone, light bluish-gray, thin-bedded; a few fragments of chert near base.....	13
Analysis of units 1-3, sampled thickness 31 feet; $CaCO_3$, 96.70; $MgCO_3$, 0.85; SiO_2, 2.00; Al_2O_3, 0.30; Fe_2O_3, 0.12; P_2O_5, 0.045; total, 100.01	
Ordovician dolomite and limestone	

Coarse-grained high-calcium limestone (Murat facies of the Lincolnshire) is largely exposed on both sides of U. S. Highway 60 from the vicinity of "Old Liberty Hall" northwestward to Whistle Creek bridge, a distance of approximatly three-fourths of a mile. Samples collected through a thickness of about 75 feet by H. D. Campbell and J. L. Howe at locality 14 show an average of 1.33 percent insoluble matter, less than one-half of one percent magnesia, and more than 98 percent calcium carbonate.[1]

High-calcium limestones of the Timber Ridge-Murat belt are well displayed in an inactive quarry (Pl. 1, loc. 15) near State Road 672 about one mile northwest of Lexington. This quarry is about 300 feet long, 250 feet wide, and 75 feet high at the northeastern end. Coarse-grained limestone, dipping 15° to 20° SE., and without noticeable clay seams or solution cavities, comprises the northeastern wall of the quarry.

Exposures are inadequate for detailed study for about two miles southwest of locality 15. Farther southwest the Ordovician limestone belt is well exposed along State Roads 674 and 670, along State Highway 251 at Murat, and in a broad area about one mile southwest of Murat. The thickness and composition of the limestones at a locality (Pl. 1, loc. 16) about 3 miles southwest of Lexington are given below.

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[1] Analyses published with permission of the owner, Dr. Richard P. Bell, Staunton, Virginia.

GEOLOGIC SECTION 12.—ALONG STATE ROAD 674 ABOUT 2 MILES NORTHEAST OF MURAT AND 3 MILES SOUTHWEST OF LEXINGTON, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone and shale	
Edinburg formation (lower part)	
20. Botetourt limestone member, dark-gray, medium-grained, rusty-weathering	22
Ordovician limestone: strike N. 45° E.; dip 35°-50° SE.	
Lincolnshire and Whistle Creek limestones (245 feet)	
19. Limestone, dark-gray, nodular	18
18. Murat limestone facies, light-gray, coarse-grained	115
17. Limestone, light-gray, medium-grained	22
16. Limestone, light-gray, medium- to coarse-grained; partly covered	18
15. Limestone, medium-gray, fine-grained	5
Analyses of units 15-18, sampled thickness 160 feet; $CaCO_3$, 97.26; $MgCO_3$, 0.94; SiO_2, 1.04; Al_2O_3, 0.36; Fe_2O_3, 0.12; total, 99.72.	
14. Largely covered; few exposures of light-gray limestone	22
13. Limestone, dark-gray, fine-grained	20
12. Covered interval under bridge; thickness estimated	10
11. Limestone, dark-gray, fine-grained, sparsely cherty	15
New Market limestone (41 feet)	
10. Limestone, light-gray, compact, cherty	15
9. Covered interval	10
8. Limestone, light-gray, compact; chert nodules and stringers	4
7. Limestone, bluish-gray, compact	10
6. Limestone with clastic chert fragments	2
Ordovician dolomite and limestone	
Beekmantown dolomite (upper 17 feet)	
5. Dolomite, light-gray, fine-grained	5
4. Chert bed	1-2
3. Dolomite, light-gray, fine-grained	4
2. Limestone, bluish-gray, fine-grained	1
1. Dolomite, light-gray, fine-grained	6

Scattered exposures along the strike of units 13 and 14 with an aggregate thickness of about 40 feet, appear to be high-calcium limestone, thus the total thickness of high-calcium limestone at this locality is about 200 feet. This thickness agrees closely with more accurate measurements at a locality about one mile northeast of Murat (Pl. 1, loc. 17) and given in the following section.

GEOLOGIC SECTION 13.—JUST EAST OF STATE ROAD 670 ABOUT 1 MILE NORTHEAST OF MURAT AND 4 MILES SOUTHWEST OF LEXINGTON, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone and shale	
Edinburg formation (lower part)	
6. Botetourt limestone member, dark-gray, medium-grained, cobbly, clayey	30
Ordovician limestone: strike N. 60° E.; dip 30°-40° SE.	
Lincolnshire and Whistle Creek limestones (290 feet)	
5. Murat limestone facies, light-gray, coarse-grained, thick-bedded; $CaCO_3$, 98.38; $MgCO_3$, 0.64; SiO_2, 0.72; Al_2O_3, 0.20; Fe_2O_3, 0.08; P_2O_5, 0.049; total, 100.069	135
4. Murat limestone facies, light-gray, coarse-grained; $CaCO_3$, 97.89; $MgCO_3$, 0.61; SiO_2, 0.92; Al_2O_3, 0.32; Fe_2O_3, 0.16; P_2O_5, 0.072; total, 99.97	65
3. Limestone, dark-gray, medium-grained; 1 foot of cherty limestone at top; $CaCO_3$, 96.50; $MgCO_3$, 1.64; SiO_2, 1.48; Al_2O_3, 0.24; Fe_2O_3, 0.08; P_2O_5, 0.08; total, 100.02	35
2. Limestone, dark-gray, sparsely cherty; nodular near base	55
New Market limestone	
1. Limestone, light-gray, compact, cherty; partly covered	68±
Ordovician dolomite and limestone	

The above described locality is considered the best along the Timber Ridge-Murat belt for study and sampling, since practically every bed is exposed (Pl. 5A). However, the thicknesses cited are subject to some possible revision, since the bedding is not well defined. This is characteristic of most occurrences of clastic thick-bedded high-calcium limestones.

The trend of the Ordovician limestone belt southwest of Murat changes from a southwesterly to a northwesterly direction by wrapping around the end of an anticline which pitches gently southwest. The character and thickness of the high-calcium limestones near the end of this structure (Pl. 1, loc. 18) are given in the following section.

GEOLOGIC SECTION 14.—ABOUT HALF A MILE SOUTH OF STATE ROAD 677 AND ONE MILE SOUTHWEST OF MURAT, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone and shale	
Edinburg formation (lower part)	
6. Botetourt limestone member, dark-gray, medium-grained, cherty; weathers rusty-brown	34
Ordovician limestone: strike N. 40° E.; dip 15° SE.	
Lincolnshire and Whistle Creek limestone: (upper 236 feet)	
5. Murat limestone facies, light-gray, coarse-grained	18

4. Limestone, dark-gray, impure	12
3. Murat limestone facies, light-gray, coarse-grained	186
2. Limestone, dark-gray, medium-grained, nodular	4
1. Murat limestone facies, light-gray, coarse-grained; base not exposed	16
Analysis of units 1-5, sampled thickness 236 feet: $CaCO_3$, 97.10; $MgCO_3$, 1.06; SiO_2, 1.32; Al_2O_3, 0.28; Fe_2O_3, 0.20; total, 99.96.	

It should be noted that units 2 and 4, with an aggregate thickness of 16 feet, are included in the above analysis, thus this may account for the relatively high silica content.

Collierstown-Rapps Mill belt.—This belt of Ordovician limestone, repeated by folding and locally disarranged by faulting, is located between Murat and Collierstown on the northwest and extends from the general vicinity of U. S. Highway 60 southwestward to a locality about 5 miles southwest of Rapps Mill (Pl. 1). Short Hill forms a natural eastern boundary of this limestone belt southwest of Murat. The following descriptions begin with locality 19 which is along Buffalo Creek about 1½ miles northwest of Murat.

GEOLOGIC SECTION 15.—ALONG BUFFALO CREEK NEAR JUNCTION OF STATE HIGHWAYS 251 AND 281 ABOUT 1½ MILES NORTHWEST OF MURAT, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone and shale	
Edinburg formation (lower part)	
17. Botetourt limestone member, dark-gray, medium-grained, cherty	28
Ordovician limestone: strike N. 20° E.; dip 40°-70° NW.	
Lincolnshire and Whistle Creek limestones (412 feet)	
16. Limestone, dark-gray, medium- to fine-grained; a few impure partings; $CaCO_3$, 89.95; $MgCO_3$, 1.58; SiO_2, 6.68; Al_2O_3, 0.36; Fe_2O_3, 0.96; total, 99.53	109
15. Murat limestone facies, light-gray, coarse-grained	98
14. Limestone, gray, cobbly, impure	13
13. Murat limestone facies, light-gray, coarse-grained	20
Analysis of units 13-15, sampled thickness 131 feet: $CaCO_3$, 96.50; $MgCO_3$, 1.18; SiO_2, 1.52; Al_2O_3, 0.24; Fe_2O_3, 0.20; total, 99.64.	
12. Limestone, dark-gray, medium-coarse-grained; about 2 feet of cherty limestone near base; $CaCO_3$, 93.31; $MgCO_3$, 1.33; SiO_2, 4.52; Al_2O_3, 0.24; Fe_2O_3, 0.28; total, 99.68	37
11. Limestone, medium- to dark-gray, medium-grained, cherty	39
10. Limestone, dark-gray, cherty	18

9. Limestone, light-gray, compact	10
8. Limestone, dark-gray, fine-grained, cherty	10
7. Limestone, light-gray; few compact beds	35
6. Limestone, dark-gray, thin-bedded, cherty	7
5. Limestone, light-gray, fine-grained	7
4. Limestone, dark-gray, fine-grained	9
New Market limestone (48 feet)	
3. Limestone, light- to dark-gray, compact; a few cherty beds	28
2. Limestone, dark bluish-gray, cherty	5
1. Limestone, light-gray, compact	15
Ordovician dolomite and limestone	

Although the greater part of the total thickness of units 12-15 in the above section is coarse-grained limestone, the occurrence of intercalated impure cobbly and cherty layers reduces the general average purity of the deposit. It is thought that units 13 and 15, with an aggregate thickness of 118 feet, represent the best grade limestone at this locality.

The character and thickness of the Ordovician limestones about two miles northeast of Buffalo Creek (Pl. 1, loc. 20) are given in the following section.

GEOLOGIC SECTION 16.— ABOUT ONE-FOURTH OF A MILE SOUTHEAST OF TOAD RUN AND 5 MILES WEST OF LEXINGTON, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone and shale	
Edinburg formation (lower part)	
18. Limestone, black; shaly partings; several hundred feet	
17. Botetourt limestone member, dark-gray, medium-grained	15
Ordovician limestone: strike N. 45° E.; dip, overturned, 75° SE.	
Lincolnshire and Whistle Creek limestones (353 feet)	
16. Limestone, dark-gray, cobbly, cherty	24
15. Limestone, dark-gray, cobbly	18
14. Limestone, dark-gray, cobbly, cherty	18
13. Limestone, dark-gray, cherty	50
12. Limestone, gray, medium-grained	9
11. Covered interval	12
10. Limestone, cobbly, impure	15
9. Limestone, medium-gray, medium-grained	24
8. Limestone, cobbly	6
7. Murat limestone facies, light-gray, medium- to coarse-grained	111
6. Covered interval	24
5. Limestone, dark-gray, cherty; contains wavy laminations	42

New Market limestone (43 feet)	
4. Limestone, light-gray, thin-bedded, compact	8
3. Siltstone (?)	4
2. Limestone, light-gray, compact	6
1. Limestone, light-gray, compact, cherty	25
Ordovician dolomite and limestone	

Although none of the rocks were sampled in the above section, it is apparent from the lithology that only units 7, 9, and 12 with an aggregate thickness of about 144 feet, would meet the requirements of high-calcium limestone.

Limestones of Ordovician age are partly exposed along State Road 672 east of its junction with State Road 673 and in a broad area along State Road 641 where the limestones wrap around the axis of a syncline pitching gently southwestward. About 60 feet of coarse-grained limestone sampled at locality 21 along the western limb of this syncline near the intersections of State Roads 672 and 676 contained 98.06 percent calcium carbonate, 0.97 percent magnesium carbonate, and 0.92 percent insoluble material.

This belt of Ordovician limestone, consisting of very cherty limestone in the lower part and coarse-grained, high-calcium limestone near the top is repeated by gentle folding along and southeast of State Road 672 for approximately a mile west of Toad Run. Some of the more pronounced displays of cherty limestone in this area are shown in Plate 4A.

The finest exposure of the belts mapped as Ordovician limestone and Ordovician limestone and shale noted in Rockbridge County is along State Highway 251 and Colliers Creek (Pl. 1, loc. 22) about 6 miles west of Lexington. The following detailed description of the rocks comprising the lower part of the Ordovician limestone belt is modified after a section by B. N. and G. A. Cooper (1946, p. 104-105).

GEOLOGIC SECTION 17.—ALONG COLLIERS CREEK AND STATE HIGHWAY 251 ABOUT 2½ MILES SOUTHEAST OF COLLIERSTOWN POST OFFICE, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone and shale	
Edinburg formation (lower part)	
53. Botetourt limestone member, dark-gray, medium-grained, rusty-weathering	8±
Ordovician limestone	
Lincolnshire limestone (235 feet)	
52. Limestone, dark bluish-gray, medium-bedded	20
51. Limestone, dark-grav, medium-grained, impure, cherty	67

50. Limestone, dark-gray, medium-grained, nodular..... 51
49. Limestone, medium-gray, coarse-grained, impure..... 5
48. Limestone, light-gray, coarse-grained..... 6
47. Limestone, dark-gray, nodular..... 11
46. Limestone, dark- to medium-gray, medium-grained..... 5
45. Limestone, light-gray, coarse-grained..... 5
44. Limestone, dark-gray, medium-grained, nodular, impure... 8
43. Limestone, light-gray, coarse-grained..... 12
Analysis of units 43, 45, and 46, sampled thickness 22 feet: $CaCO_3$, 97.10; $MgCO_3$, 0.64; SiO_2, 1.52; Al_2O_3, 0.36; Fe_2O_3, 0.08; total, 99.70.
42. Limestone, dark-gray, impure, sparsely cherty..... 40
41. Limestone, light- to medium-gray, coarse-grained..... 5

Whistle Creek limestone (165 feet)

40. Limestone, dark-gray, medium- to fine-grained; contains siliceous partings and weathers rusty-brown..... 22
39. Limestone, dark-gray, medium- to coarse-grained, sparsely cherty 8
38. Limestone, cherty; weathers brown..... 4
37. Limestone, medium-gray, medium-grained, even-bedded.... 11
36. Limestone, dark-gray, medium-grained..... 30
35. Limestone, medium-gray, medium-grained; contains a few siliceous partings 29
34. Limestone, gray, medium-grained, nodular..... 6
33. Limestone, dark bluish-gray, medium-grained, very cherty 4
32. Limestone, dark bluish-gray, medium-grained..... 9
31. Limestone, dark bluish-gray, medium-grained, very cherty. 9
30. Limestone, dark-gray, fine-grained, sparsely cherty; contains few irregular impure partings (Pl. 5C)..... 33

New Market limestone (120+ feet)

29. Limestone, light-gray, compact..... 3.5
28. Limestone, light-gray, clastic..... 3.7
27. Limestone, dark-gray 0.3
26. Limestone, light-gray, compact..... 2.0
25. Limestone, clayey, sparsely cherty..... 5.4
24. Limestone, medium-gray, fine-grained, cherty..... 1.4
23. Limestone, dark-gray, very cherty..... 1.7
22. Limestone, medium- to light-gray, compact to fine-grained, sparsely cherty 30.0
21. Limestone, dark-gray, fine-grained..... 5.3
20. Limestone, light-gray, compact, even-bedded..... 5.3
19. Limestone, dark-gray, fractured..... 1.8
18. Limestone, dark-gray, cherty..... 4.5
17. Limestone, light- to dark-gray, mottled..... 4.0
16. Limestone, light-gray, compact; a few thin clayey partings.. 4.4
15. Limestone, light-gray, compact..... 1.3
14. Limestone, light- to dark-gray, mottled..... 12.0
13. Limestone, compact; weathers smoke-gray..... 0.6

12. Limestone, clastic	0.2
11. Shale	0.2
10. Limestone, light-gray, compact	11.4
9. Limestone, dolomitic; weathers drab-gray	1.0
8. Limestone, dark-gray, compact, laminated	1.6
7. Limestone, dark-gray, banded; contains small grains of pyrite	2.4
6. Dolomite, drab-gray, impure	1.7
5. Limestone, dolomitic, bluish-gray; weathers buff	0.9
4. Limestone, drab-gray, impure; contains small fragmants of limestone and chert	0.9
3. Limestone, dark-gray, compact; a few curly buff partings of impure limestone	5.0
2. Limestone, dark-gray, fine-grained, even-bedded	6.0
1. Dolomite; contains pebbles of dolomite, limestone, and chert	2.0
Analysis of units 1-29, exclusive of shale and chert beds, sampled thickness 120 feet: $CaCO_3$, 90.24; $MgCO_3$, 2.48; SiO_2, 6.20; Al_2O_3, 0.56; Fe_2O_3, 0.12; total, 99.60.	

Ordovician dolomite and limestone

High-calcium limestone in the above section is restricted to several thin layers (Pl. 5B) intercalated with impure rocks. It is reasonably certain that none of these occurrences are of commercial value. Farther southwestward along this belt the coarse-grained limestones thicken to about 76 feet (Pl. 1, loc. 23).

GEOLOGIC SECTION 18.—ALONG AND EAST OF STATE ROAD 611 ABOUT 3 MILES SOUTHWEST OF MURAT, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone and shale	
Edinburg formation (lower part): strike N. 8° E.; dip 28° SE.	
13. Botetourt limestone member, dark-gray, medium-grained; weathers rusty-brown	15
Ordovician limestone	
Lincolnshire and Whistle Creek limestones (391 feet)	
12. Limestone, dark bluish-gray, fine- to medium-grained, cherty	48
11. Limestone, dark-gray, medium-grained, impure; weathers nodular	22
10. Limestone, dark-gray, nodular, cherty	43
9. Limestone, dark-gray, coarse-grained. impure	15
8. Murat limestone facies, light-gray, coarse-grained; contains few irregular masses of compact limestone	19
7. Limestone, medium-grained, nodular	12
6. Murat limestone facies, light-gray, coarse-grained	45
Analysis of units 6-8, sampled thickness 76 feet: $CaCO_3$, 97.30; $MgCO_3$, 0.55; SiO_2, 1.40; Al_2O_3, 0.16; Fe_2O_3, 0.20; total, 99.61.	

5. Limestone, dark-gray, coarse-grained, nodular, impure....	3
4. Limestone, dark bluish-gray, fine- to medium-grained, cherty	159
3. Limestone, dark-gray, cherty.....	25
New Market limestone (upper 27 feet)	
2. Limestone, drab-gray, laminated, cherty.....	12
1. Limestone, light-gray, compact; covered at base.....	15
Ordovician dolomite and limestone	

Approximately 58 feet of light-gray, coarse-grained limestone, similar to unit 6 in the above section, crops out about one-fourth of a mile southeast of State Road 611 and 3½ miles southwest of Murat (Pl. 1, loc. 24). It is thought that this limestone unit thins rapidly in a southwesterly direction, since it was not observed in the vicinity of Rapps Mill or in the area southwest of the Rockbridge-Botetourt County line. The following description of the Ordovician limestones exposed near the southwestern end of the Rapps Mill belt (Pl. 1, loc. 25), is modified after a section published by B. N. and G. A. Cooper (1946, p. 106).

GEOLOGIC SECTION 19.—ABOUT HALF A MILE SOUTH OF DUNKARD CHURCH AND 4 MILES SOUTHWEST OF RAPPS MILL, BOTETOURT COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone and shale	
Edinburg formation (lower part)	
7. Botetourt limestone member (type section)	
c. Shale and limestone; deeply weathered.....	6
b. Limestone, rusty-brown, coarse-grained.....	18
a. Limestone, rusty-brown, nodular, clayey; contains few thin beds of coarse-grained limestone.....	42
Ordovician limestone: strike N. 30° E.; dip 20°-30° SE.	
Lincolnshire and Whistle Creek limestones (266 feet)	
6. Limestone, dark-gray, nodular, cherty.....	157
5. Limestone, medium-gray, medium- to coarse-grained.....	17
4. Limestone, dark-gray, nodular.....	13
3. Limestone, dark-gray, nodular; contains a few thin coarse beds	22
2. Limestone, dark bluish-gray, cherty.....	57
New Market limestone	
1. Limestone, dove-gray, compact, cherty.....	20
Ordovician dolomite and limestone	

High-calcium limestone in the above section is restricted to several thin intercalated beds. It is reasonably certain that none of these occurences are of commercial value.

Limestones comprising the western part of the Collierstown-Rapps Mill belt extend from the end of pitching anticline about 1½ miles southwest of locality 25 northeastward to an overthrust fault 2 miles east of Collierstown. Approximately 50 feet of high-calcium limestone is exposed near the northeastern end of this belt about 2 miles east of Collierstown (Pl. 1, loc. 26).

The thickness and composition of the rocks in the upper part of the section along Colliers Creek (Pl. 1, loc. 27) about one mile southwest of locality 26 are given in the following section.

GEOLOGIC SECTION 20.—ALONG STATE HIGHWAY 251 AND COLLIERS CREEK ABOUT 1 MILE SOUTHEAST OF COLLIERSTOWN, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone: strike N. 43° E.; dip 30° SE.	
Lincolnshire and Whistle Creek limestones (upper 110 feet)	
4. Limestone, dark-gray, medium-grained, nodular	7
3. Limestone, light- to medium-gray, fine- to coarse-grained	9
2. Murat limestone facies, light-gray, coarse-grained	47
Analysis of units 2-3, sampled thickness 56 feet: $CaCO_3$, 97.66; $MgCO_3$, 1.15; SiO_2, 1 12; Al_2O_3, 0.24; Fe_2O_3, 0.16; total, 100.33.	
1. Limestone, dark-gray, medium-grained	47

Farther southwest the rocks comprising the belt of Ordovician limestone are partially exposed at several localities along Spring Branch southwest of its junction with the North Fork of Buffalo Creek. The following section was compiled from two localities (Pl. 1, locs. 28 and 29) in this area.

GEOLOGIC SECTION 21.—ORDOVICIAN LIMESTONE ALONG SPRING BRANCH ABOUT 2½ MILES NORTHEAST OF RAPPS MILL, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone: strike N. 10° W.; dip 15°-20° NE.	
Lincolnshire and Whistle Creek limestones (297 feet)	
6. Limestone, dark-gray, cobbly, impure	12
5. Murat limestone facies, light-gray, coarse-grained; $CaCO_3$, 97.26; $MgCO_3$, 0.86; SiO_2, 1.12; Al_2O_3, 0.40; Fe_2O_3, 0.12; total, 99.76	60
4. Limestone, dark-gray, fine-to medium-grained, cherty; partly covered, thickness estimated	225
New Market limestone (49 feet): strike N. 30° E.; dip 22° SE.	
3. Limestone, light bluish-gray, compact; a few buff-weathering clayey partings and chert fragments	31

2. Limestone, light bluish-gray, compact, cherty at base.....	10
1. Limestone, light- to bluish-gray, mottled, clayey; a few small chert fragments.....	8
Analysis of units 1-3, sampled thickness 49 feet: $CaCO_3$, 88.59; $MgCO_3$, 3.70; SiO_2, 6.56; Al_2O_3, 0.52; Fe_2O_3, 0.28; total, 99.65.	
Ordovician dolomite and limestone	

Immediately above unit 6 in the above section at locality 28 is about 10 feet of dark-gray, rusty-weathering Botetourt limestone. This limestone is succeeded, although partly covered, by about 285 feet of black, shaly limestone of the Edinburg formation.

A few small scattered exposures of Ordovician limestone were observed along State Roads 612 and 661 west of Spring Branch, but none of these outcrops were adequate for detailed study. Farther northwestward, at locality 30 about 1½ miles southwest of Collierstown Post Office, the lower 100 feet of limestone in this belt is composed of light-gray, compact, cherty limestone. An examination of the rocks in the localities cited, although restricted because of incomplete exposures, suggests that there are no thick deposits of high-calcium limestone in the Collierstown-Rapps Mill belt southwest of Collierstown.

Zack-Kerrs Creek belt.—This belt of Ordovician limestone, locally modified by folding and offset by cross faulting northwest of Brownsburg, extends from a locality about 5 miles northeast of Newport, Augusta County, southwestward to the general vicinity of Kerrs Creek, Rockbridge County. The Zack-Kerrs Creek belt of Ordovician limestone has a length of approximately 20 miles, passing east of Zack and crossing State Highway 39 about one mile west of Rockbridge Baths (Pl. 1).

The character and thickness of the Ordovician limestones near the northeastern end of the belt in Augusta County are given in the following section (Pl. 1, loc. 31).

GEOLOGIC SECTION 22.—ORDOVICIAN LIMESTONE ALONG STATE ROAD 603 ABOUT 5 MILES NORTHEAST OF NEWPORT, AUGUSTA COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone: strike N. 80° W.; dip 37° NE.	
Lincolnshire and Whistle Creek limestones (341 feet)	
4. Limestone, dark-gray, fine- to medium-grained, cherty....	138
3. Limestone, light-gray, compact.....	3
2. Partly covered; a few exposures of dark-gray, fine- to medium-grained, cherty limestone.....	200±

New Market limestone

1. Partly covered; a few exposures of light-gray, compact, cherty limestone 50-75

Ordovician dolomite and limestone

The estimated thickness of units 1 and 2 in the above section is based partly upon observations of the lower part of the Ordovician limestone belt at locality 32 where the following section is fully exposed.

GEOLOGIC SECTION 23.—ORDOVICAN LIMESTONE ALONG STATE ROAD 602 ABOUT 4 MILES NORTHEAST OF ZACK, AUGUSTA COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone: strike N. 34° E.; dip, overturned, 75° SE.	
Lincolnshire and Whistle Creek limestones (360 feet)	
6. Limestone, dark-gray, nodular; contains thin siliceous partings	75
5. Limestone, dark-gray, medium-grained, sparsely cherty	51
4. Limestone, light-gray, compact	5
3. Limestone, dark-gray, fine- to medium-grained, cherty	229
New Market limestone (69 feet)	
2. Limestone, light-gray, fine-grained to compact, sparsely cherty; contains thin buff-weathering bands	14
1. Limestone, light-gray, banded; contains thin intercalations of impure buff-weathering dolomite; lower boundary uncertain	55
Ordovician dolomite and limestone	

The Ordovician limestone belt is well exposed along State Road 681 about 2 miles northeast of Zack (Pl. 1, loc. 33), but due to minor folding it is difficult to measure the thickness. The beds along the contact with the Beekmantown dolomite are overturned 45 degrees to the southeast; whereas the upper part of the section is essentially vertical. Of special significance at this locality is the occurrence of about 40 feet of light-gray, medium-grained limestone which was not noted at any of the localities along the strike to the northeast.

High-calcium limestone, of similar lithology, crops out at several localities in the general vicinity of Zack. The character and thickness of one of these belts which comprise the west limb of a small anticline along State Road 725 are given in the following section (Pl. 1, loc. 34).

GEOLOGIC SECTION 24.—ORDOVICIAN LIMESTONE ALONG AND NEAR STATE ROAD 725 ABOUT 1 MILE NORTHEAST OF ZACK, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone and shale	
Edinburg formation (lower part)	
4. Botetourt limestone member, dark-gray, medium-grained; weathers rusty-brown	23
Ordovician limestone: strike N. 37° E.; dip, vertical	
Lincolnshire and Whistle Creek limestones (upper 98 feet)	
3. Limestone, dark-gray, medium-grained, impure	30
2. Murat limestone facies, light-gray, coarse-grained; $CaCO_3$, 98.26; $MgCO_3$, 0.55; SiO_2, 0.56; Al_2O_3, 0.28; Fe_2O_3, 0.12; total, 99.77	68
1. Limestone, dark-gray, fine- to medium-grained, cherty; exposed along crest of small anticlinal fold; thickness undetermined.	

The belt of Ordovician limestone, although shifted to the west by two small folds, continues in a southwesterly direction passing just east of Zack where the following section is exposed (Pl. 1, loc. 35).

GEOLOGIC SECTION 25.—NEAR STATE ROAD 602 ABOUT ONE-FOURTH OF A MILE SOUTHEAST OF ZACK, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone: strike N. 37° E.; dip, vertical	
Lincolnshire and Whistle Creek limestones (360 feet)	
7. Limestone, dark-gray, nodular cherty	65
6. Limestone, dark-gray, coarse-grained	15
5. Murat limestone facies, light-gray, coarse-grained; contains algal structures	26
4. Limestone, dark-gray, medium-coarse-grained, cherty	12
3. Limestone, dark-gray, fine- to medium-grained, cherty	65
2. Limestone, dark-gray, medium-grained	9
1. Limestone, dark-gray, fine- to medium-grained	168
New Market limestone	

Although no samples were analyzed from the above section, it is probable that units 2, 5, and 6 contain more than 95 percent calcium carbonate. No thick occurrences of high-calcium limestone were noted along the Ordovician limestone belt from the vicinity of Zack southwestward to State Road 724. The general character of the rocks, perhaps including about two-thirds of the total thickness of the Ordovician limestone belt, at a locality about midway between Zack and Jump (Pl. 1, loc. 36), is given in the following section.

GEOLOGIC SECTION 26.—ABOUT HALF A MILE WEST OF STATE ROAD 731 AND 1½ MILES SOUTH OF ZACK, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone: strike N. 30° E.; dip, overturned, 45° SE.	
Lincolnshire and Whistle Creek limestones (lower 150 feet)	
7. Limestone, dark-gray, fine- to medium-grained, cherty....	138
6. Limestone, light- to dark-gray, fine-grained to compact....	12
New Market limestone (67 feet)	
5. Limestone, light-gray, compact; a few thin beds of dark-gray, cherty limestone.....	18
4. Limestone, medium-gray, compact.....	7
3. Limestone, dark-gray, cherty.....	8
2. Limestone, gray, compact, striped.....	10
1. Limestone, dark bluish-gray, striped, impure; a few thin beds of impure dolomite near base.....	24
Ordovician dolomite and limestone	

The structure of the Ordovician limestone belt between Brownsburg and Rockbridge Baths is shown on the Geologic Map of the Appalachian Valley as an anticline overridden on the southeast side by Cambrian dolomite and limestone and offset by a cross fault near State Road 724 at the northeastern end. Additional work by the writer in the vicinity of Brownsburg suggests that the overthrust sheet has been locally eroded through exposing younger rocks beneath and giving rise to a fentser. Dark-gray, rusty-weathering Botetourt limestone crops out along State Road 724 at the intersection of State Road 731 (Pl. 1, loc. 37). An estimated 50 feet of high-calcium limestone, underlying the impure rocks mentioned above, is exposed on a low hill 200 yards southwest of locality 37 and along State Road 731 about 100 yards farther southwest. Apparently, this is a local occurrence of high-calcium limestone, since all of the limestones are impure at locality 38, about 1½ miles southwest of State Road 724.

The character and thickness of the Ordovician limestones along State Road 731 are given in the following section (Pl. 1, loc. 38).

GEOLOGIC SECTION 27.—ALONG STATE ROAD 731 ABOUT 2 MILES NORTHEAST OF ROCKBRIDGE BATHS, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone: strike N. 54° E.; dip, overturned, 74° SE.	
Lincolnshire and Whistle Creek limestones (139 feet)	
2. Limestone, medium- to dark-gray, fine- to medium-grained, cherty	139

New Market limestone

1. Limestone, light-gray, compact to fine-grained, sheared; $CaCO_3$, 93.53; $MgCO_3$, 2.21; SiO_2, 4.04; Al_2O_3, 0.32; Fe_2O_3, 0.16; total, 100.26 48

Ordovician dolomite and limestone

The thickness of the Ordovician limestones remains about the same along the strike to the southwest for a distance of 500 feet, but only about 15 feet of New Market was measured. This rather sudden change in thickness is common in the New Market limestone, since it lies unconformably upon the Beekmantown dolomite.

Incomplete exposures of the Ordovician limestone belt, chiefly cherty limestone, were observed at locality 39 about one-fourth of a mile east of State Road 623 and 3 miles southwest of Rockbridge Baths. Farther southwestward in the area southeast of Kerrs Creek School, the belt of Ordovician limestone wraps around the end of a southwesterly plunging anticline and continues eastward to an overthrust fault which crosses State Road 631 just east of the bridge over Kerrs Creek. In this area there are conspicuous layers of coarse-grained limestone, some of which probably are of sufficient thickness to warrant small-scale operations. The general character of the upper part of the belt of Ordovician limestone just south of Kerrs Creek (Pl. 1. loc. 40) is given in the following section.

GEOLOGIC SECTION 28.—ABOUT 1000 FEET SOUTH OF THE INTERSECTION OF STATE ROADS 623 AND 631 AND 1 MILE EAST OF KERRS CREEK SCHOOL ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone and shale	
Edinburg formation (lower part)	
10. Botetourt limestone member, dark-gray, medium-grained, rusty-weathering	30
Ordovician limestone	
Lincolnshire and Whistle Creek limestones (upper 268 feet)	
9. Limestone, dark-gray, fine-grained, cherty.....	65
8. Covered interval	20
7. Limestone, fine-grained, sparsely cherty; contains few layers of coarse-grained high-calcium limestone.....	60
6. Covered interval	15
5. Limestone, medium-grained, rusty-weathering.....	15
4. Largely covered	15
3. Limestone, dark-gray, fine-grained, cherty.....	40
2. Limestone, medium-gray, medium-grained.....	18
1. Limestone, medium-gray, medium-grained, sparsely cherty; covered at the base	20

The following section with practically every bed exposed is displayed along Kerrs Creek (Pl. 1, loc. 41) about half a mile east of locality 40.

GEOLOGIC SECTION 29.—ALONG KERRS CREEK JUST EAST OF THE CROSSING OF STATE ROAD 631, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone: strike N. 30° E.; dip, overturned, 25°-40° SE.	
Lincolnshire and Whistle Creek limestones (lower 172 feet)	
14. Limestone, dark-gray, fine-grained; covered at the top.....	10
13. Limestone, dark-gray, cherty.....	5
12. Limestone, medium-gray, fine- to medium-grained; few thin irregular siliceous partings; $CaCO_3$, 93.03; $MgCO_3$, 1.64; SiO_2, 4.52; Al_2O_3, 0.60; Fe_2O_3, 0.36; total, 100.15.....	40
11. Murat limestone facies, light-gray, medium- to coarse-grained	22
10. Limestone, dark-gray, fine-grained, impure, gnarly weathering	5
9. Murat limestone facies, gray, medium-grained.....	5
Analysis of units 9-11, sampled thickness 32 feet: $CaCO_3$, 97.06; $MgCO_3$, 0.85; SiO_2, 1.64; Al_2O_3, 0.32; Fe_2O_3, 0.08; total, 99.95	
8. Limestone, dark-gray, cobbly, cherty.....	10
7. Limestone, dark-gray, fine-grained, impure, gnarly weathering	40
6. Limestone, dark-gray, cobbly-weathering.....	10
5. Limestone, dark-gray, compact to fine-grained; boundary uncertain; may belong with underlying unit.....	25
New Market limestone (73 feet)	
4. Limestone, light-gray, compact to fine-grained.....	10
3. Limestone, cobbly, impure.....	3
2. Limestone, light-gray, compact to fine-grained; contains cherty zones at intervals of 5 to 10 feet.....	45
1. Covered interval	15
Ordovician dolomite and limestone	

Steeles Tavern-Buffalo Creek belt.—Small discontinuous exposures, containing high-calcium limestone, occur near the trace of the Pulaski-Staunton fault northwest of Steeles Tavern, crossing Buffalo Creek about 4 miles southwest of Lexington, and along Purgatory Creek about 2½ miles north of Buchanan (Pl. 1). Another small detached belt of Ordovician limestone occurs in the vicinity of Brownsburg, but field study shows that this area does not contain quarryable thicknesses of high-calcium limestone.

Ordovician limestone northwest of Steeles Tavern is partly ex-

posed from the vicinity of Moores Creek northeastward to a locality about half a mile northeast of the Augusta-Rockbridge County line, a distance of two miles. The thickness and composition of the limestones near the northeastern end of this belt at the Cyrus McCormick Museum (Pl. 1. loc. 42) are as follows:

GEOLOGIC SECTION 30.—AT THE CYRUS MCCORMICK MUSEUM ABOUT THREE-FOURTHS OF A MILE NORTHWEST OF STEELES TAVERN, AUGUSTA COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone	
Lincolnshire and Whistle Creek limestones	
2. Limestone, dark-gray, medium-grained, cherty; covered at the top	50
New Market limestone	
1. Limestone, light bluish-gray, compact, sheared; $CaCO_3$, 97.06; $MgCO_3$, 1.60; SiO_2, 1.12; Al_2O_3, 0.48; Fe_2O_3, 0.08; total, 100.34	50
Ordovician dolomite and limestone	

Ordovician limestones were observed at several localities between the Augusta-Rockbridge County line and State Road 706, but the exposures were not adequate for accurate determination of thickness. The belt of Ordovician limestone southwest of State Road 706 and about half a mile northeast of the county line is overridden by older dolomites along the Pulaski-Staunton fault.

Farther southwest discontinuous deposits of high-calcium limestone, occurring along the trace of the Pulaski-Staunton fault, were observed along and east of U. S. Highway 11 about 4 miles southwest of Lexington and along Buffalo Creek at several localities about 2½ miles southeast of Murat (Pl. 1). It is estimated that there is about 100 feet of coarse-grained limestone exposed in a vertical cliff along State Road 610 and Buffalo Creek (Pl. 1, loc. 43). Although the rocks at this locality could not be examined in detail, thin zones of dark-gray limestone containing black chert were noted at the base, near the middle, and at the top of the exposure. Immediately above and forming the rim of the cliff are Beekmantown dolomite and limestone which have been thrust upon the younger limestones. Faulting is also indicated at a locality about one-fourth of a mile to the southwest where the dolomite is in contact with the Edinburg shaly limestone. At locality 44, about one-fourth of a mile east of the junction of State Roads 610 and 678, the Ordovician limestones are well displayed in the bluff of Buffalo Creek. Here approximately 100 feet of Murat limestone con-

tains 98.78 percent calcium carbonate, 0.40 percent magnesium carbonate, and 0.71 percent insoluble matter. Partial exposures of these high-calcium limestones were observed for about 1,000 feet southwestward along the strike. Beyond this point, the Beekmantown dolomite is again in contact with the Edinburg shaly limestone.

The Valley of Virginia in the vicinity of Buchanan narrows to not more than two miles, being limited on the west by Purgatory Mountain and on the east by the Blue Ridge. High-calcium limestone is well displayed along and east of Purgatory Creek (Pl. 1, loc. 45) about 2½ miles slightly northeast of Buchanan, Botetourt County. Although the structure in this area is uncertain, the general distribution of the limestone units suggests that they occur as faulted slices along branch faults of the Pulaski-Staunton overthrust.

Exposures of Ordovician limestone extend from a low hill about half a mile southwest of State Road 611 northeastward along the strike across State Road 611 to a point about one-fourth of a mile southeast of Gray Ledge, a distance of approximately one mile. The belt is terminated at the northeast and southwest by a branch fault of the Pulaski-Staunton fault. Since beds of similar lithology occur at several horizons within the exposure along Purgatory Creek for a traverse distance of approximately 1,000 feet, it is thought that some of the units have been repeated by faulting. To assume a normal geologic sequence at this locality would involve the occurrence of high-calcium limestone in far greater thicknesses than known elsewhere in the Valley of Virginia.

Analyses of three units (Table 7, loc. 45) sampled along Purgatory Creek, each representing approximately 150 feet of limestone, show more than 95 percent calcium carbonate.

Southwest of Buchanan the Valley of Virginia widens to about 10 miles and maintains this average width in a southwesterly direction to Tinker Mountain, a distance of about 15 miles. This division of the Valley of Virginia has been named by Stose (1922, p. 8) Fincastle Valley, from the town of Fincastle near its center.

Ordovician limestone, locally containing deposits of high-calcium limestone, occurs in two belts—the Fincastle belt north and west of Fincastle and the Eagle Rock belt, a faulted slice along the Pulaski-Staunton fault in the western part of the valley.

Fincastle belt.—The Fincastle belt of Ordovician limestone is exposed on the flanks of a basin-like syncline located north and west of the town of Fincastle (Pl. 1). The middle part, or trough, of this fold contains Ordovician limestone and shale. Minor faults occur near U. S.

Highway 220, about 2 miles north of Kyles Mill, and in the vicinity of Fincastle. The character and thickness of the Ordovician limestones near the northeastern end of the syncline (Pl. 1, loc. 46) are given in the following section.

GEOLOGIC SECTION 31.—NEAR U. S. HIGHWAY 220 ABOUT 1½ MILES NORTHWEST OF KYLES MILL, BOTETOURT COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone: strike N. 43° E.; dip, vertical	
Lincolnshire limestone (149 feet)	
4. Limestone, dark-gray, nodular-weathering, sparsely cherty..	112
3. Limestone, dark-gray, medium-grained; contains impure thin wavy partings	13
2. Murat limestone facies, light-gray, coarse-grained.....	24
New Market (?) limestone	
1. Limestone, dark-gray, impure, nodular-weathering.....	33
Ordovician dolomite and limestone	

Although no samples for chemical analyses were collected here, it is thought that only unit 2, with a thickness of 24 feet, would meet the specifications of high-calcium limestone as defined in this report. Of particular importance is the fact that not a single bed of New Market lithology such as overlies the Beekmantown dolomite in the vicinity of Fincastle, was noted at this locality. However, Dr. B. N. Cooper (oral communication, 1957) suggests that bed number 1 in the above section may be the New Market horizon. Partial exposures of Ordovician limestones were noted along State Road 606 and at the intersection of State Roads 600 and 666.

The character and thickness of the rocks comprising the Fincastle belt along State Road 670 southwest of Fincastle (Pl. 1, loc. 47) are given in the following sections.

GEOLOGIC SECTION 32.—JUST WEST OF STATE ROAD 670 NEAR CROSSING OF CATAWBA CREEK ABOUT 2 MILES SOUTHWEST OF FINCASTLE, BOTETOURT COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone: strike N. 75° E.; dip 45° N.W.	
Lincolnshire limestone (176 feet)	
5. Limestone, ash-gray, nodular, crumbly-weathering.....	105
4. Limestone, dark-gray, fine- to medium-grained; contains thin wavy impure partings.....	71
New Market limestone (65 feet)	
3. Limestone, light-gray, compact; $CaCO_3$, 93.03; $MgCO_3$, 4.94; SiO_2, 2.04; Al_2O_3, 0.12; Fe_2O_3, 0.24; total, 100.37.....	51

2. Limestone, light-gray to buff-colored, compact, impure....	14
Ordovician dolomite and limestone	
Beekmantown dolomite (upper part)	
1. Dolomite, medium-gray; a few thin beds of bluish-gray limestone	200

The belt of Ordovician limestone, although disarranged by faulting in the vicinity of Fincastle, continues in a northeasterly direction, crossing State Road 630 east of Fincastle and State Road 635 in the vicinity of Kyles Mill. The best exposures noted in the Fincastle area are given in the following section (Pl. 1, loc. 48).

GEOLOGIC SECTION 33.—ALONG STATE ROAD 630 ABOUT 1 MILE EAST OF FINCASTLE, BOTETOURT COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone: strike N.-S.; dip 30° W.	
Lincolnshire limestone (88 feet)	
8. Limestone, dark-gray, fine-grained; covered at top.....	10
7. Limestone, dark-gray, nodular, crumbly-weathering, sparsely cherty	24
6. Limestone, dark-gray, fine-grained, nodular.....	29
5. Limestone, dark-gray; a few impure partings and chert fragments	25
New Market limestone (106 feet)	
4. Limestone, light-gray, compact; $CaCO_3$, 94.04; $MgCO_3$, 2.97; SiO_2, 2.16; Al_2O_3, 0.52; Fe_2O_3, 0.16; P_2O_5, 0.016; total, 99.86	72
3. Limestone, light-gray, impure	14
2. Limestone, light-gray, magnesian.....	9
1. Limestone, banded, conglomeratic; lower boundary uncertain	11
Ordovician dolomite and limestone	

The data give in Geologic Sections 32 and 33 show that the belt of Ordovician limestone in the general vicinity of Fincastle contains from 50 to 75 feet of New Market limestone which averages about 97 percent total carbonates and from about 93 to 94 percent calcium carbonate. Coarse-grained, high-calcium limestones, such as occur along the northwest limb of the syncline north of Fincastle (Pl. 1, loc. 46), are too thin to be considered of commercial importance.

Eagle Rock belt.—The Eagle Rock belt of Ordovician limestone, locally containing high-calcium limestone, is in an area of complicated structures (Pl. 1). It is a relatively narrow belt of limestone extending

from the vicinity of Eagle Rock southwestward for about 10 miles along or near the trace of the Pulaski-Staunton fault. Woodward has described the Salem block of the Pulaski overthrust (1935, p. 321-333) and the fault-line phenomena near Eagle Rock (1936, p. 135-142) which includes the northeastern part of the belt that has been extensively quarried and mined. Farther southwestward, the Ordovician limestones crop out near the middle of a wedge-shaped block, lying between the main fault on the east and one of its branches on the west that begins at a point about 5 miles northwest of Fincastle and extends northeastward for about three miles beyond James River. The line of faulting, marked by the trace of the Pulaski-Staunton fault, or by this fault and associated minor faults, extends in a northeasterly direction along the northwestern side of Fincastle Valley to a locality about three miles east of Eagle Rock and then swings abruptly southeastward, passing around the southern end of Purgatory Mountain near Buchanan.

There was no production of high-calcium limestone in the Eagle Rock area when visited in 1957. However, at the time of the survey in 1945, the Eagle Rock Lime Company was operating a quarry along the west side of U. S. Highway 220 about one mile southwest of Eagle Rock Station. Older workings by the Moore Lime Company, Virginia Products Company, and by the Eagle Rock Lime Company include two large quarries (Pl. 1, loc. 50) and a mine (Pl. 1, loc. 49) which are located along the belt of Ordovician limestone between U. S. Highway 220 and James River.

The last quarry to be operated by the Eagle Rock Lime Company (Pl. 1, loc. 51) is estimated to be 1,000 feet long, 250 feet wide, and has a maximum depth of about 90 feet along the southeastern face. The rocks exposed in the quarry and along U. S. Highway 220 to the east are overturned, dipping about 35° SE. Beekmantown dolomite which crops out along the eastern side of the highway appears to be in normal geologic sequence with the Ordovician limestone, including 25 feet of typical New Market limestone. However, east of the highway the New Market limestone and the overlying nodular limestones in the lower part of the Lincolnshire thin rapidly and in the limestone mine (Pl. 1, loc. 49) the Beekmantown dolomite, forming the hanging wall, is resting directly upon the coarse-grained high-calcium limestones (Pl. 3B). Faulting is discussed by Woodward (1936, p. 135-142) to explain the discordant stratigraphic sequence.

The best exposures of the Ordovician limestone belt in the Eagle

Rock area are along U. S. Highway 220 and in the adjacent inactive quarry of the Eagle Rock Lime Company (Pl. 1, loc. 51).

GEOLOGIC SECTION 34.—ALONG U. S. HIGHWAY 220 AND IN THE INACTIVE QUARRY OF THE EAGLE ROCK LIME COMPANY ABOUT 1 MILE SOUTHWEST OF EAGLE ROCK STATION, BOTETOURT COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone: strike N. 25° E.; dip, overturned, 35° SE.	
Ordovician limestone of uncertain age[1]	
5. Limestone, gray to light buff-colored, medium-grained; exposed along floor and west wall of quarry	42
4. Limestone, light-gray, coarse-grained	70
Analyses of units 4 and 5, sampled thickness 112 feet: $CaCO_3$, 97.65; $MgCO_3$, 0.95; SiO_2, 0.43; Al_2O_3, 0.69; Fe_2O_3, 0.26; total, 99.98	
3. Limestone, light-gray, compact	3
Lincolnshire limestone	
2. Limestone, dark-gray, fine- to medium-grained, nodular, cherty; contains abundant fossils	45
Analysis of units 2 and 3, sampled thickness 48 feet: $CaCO_3$, 86.17; $MgCO_3$, 1.65; SiO_2, 9.77; Al_2O_3, 1.16; Fe_2O_3, 0.62; total, 99.37	
New Market limestone	
1. Limestone, light-gray, compact; partly covered by highway; $CaCO_3$, 96.54; $MgCO_3$, 1.61; SiO_2, 1.03; Al_2O_3, 0.01; Fe_2O_3, 0.72; total, 99.91	25
Ordovician dolomite and limestone	

[1] Dr. B. N. Cooper, who has made faunal studies in this area, suggests (Oral communication, 1957) that until better correlation is possible these rocks should be referred to as "Ordovician limestone of uncertain age."

The belt of Ordovician limestone is largely covered from the vicinity of the Eagle Rock Lime Company quarry southwestward to State Road 682 where the following section was measured (Pl. 1, loc. 52).

GEOLOGIC SECTION 35.—ABOUT 100 YARDS NORTHEAST OF STATE ROAD 682 AND FOUR-TENTHS OF A MILE NORTHWEST OF ITS INTERSECTION WITH STATE ROAD 681, BOTETOURT COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone and shale	
Edinburg formation (lower part)	
4. Shale and limestone, dark-colored; includes about 8 feet of granular, rusty-weathering Botetourt (?) limestone at the base.	

Ordovician limestone: strike N. 65°-75° E.; dip, overturned, 45°-60° SE.

Ordovician limestone of uncertain age	
3. Limestone, light-gray, medium- to coarse-grained.....	75
Lincolnshire limestone	
2. Limestone, dark-gray, fine-grained, cobbly, cherty.....	38
New Market limestone	
1. Limestone, dove-gray, compact to granular.....	25

Ordovician dolomite and limestone

Partial exposures of Ordovician limestones near the southwestern end of the belt (Pl. 1, loc. 53) are thought to be of similar composition to those described at locality 52 and sampled along the U. S. Highway 220 at the Eagle Rock Lime Company quarry.

Outlying areas of Ordovician limestone associated with anticlinal folds in the western part of the James River district are described in this report as the Warm Springs Valley belt and the Rich Patch belt.

Warm Springs Valley belt.—The median part of Warm Springs Valley, extending from the vicinity of Warm Springs, Bath County, southwestward to a point about 3 miles southeast of Falling Springs, Alleghany County, is occupied by carbonate rocks of Ordovician age. The following description of the geology, exclusive of the geologic sections and chemical analyses, is a summary of a manuscript prepared by Dr. Charles Butts:

> The outcrop of the Mosheim borders that of the Beekmantown dolomite. The Beekmantown crops out in the middle of the valley from the vicinity of Falling Springs Church northeastward to Healing Springs. At the south end of the valley, opposite Falling Springs Church, the outcrop is split into two prongs by a synclinal area of the overlying impure Lenoir limestone. Northward two bands 400 to 600 feet wide border the Beekmantown on both sides to a point east of Healing Springs village where they combine and continue northward as a single band to a point nearly 1½ miles north of Mitchelltown where the Mosheim pitches beneath the Lenoir limestone. The largest area of Mosheim is in the south end of the valley on an east-west line through Falling Springs Church. The thickness as computed from the width of outcrop and the angle of dip, is about 140 feet. The overlying Lenoir is a dark to nearly black, finely crystalline limestone. Its layers are more or less irregularly laminated and on weathering tend to break down into ragged lenses, or they are commonly com-

posed of small irregular nodules of limestone invested with anastomosing clayey laminae. The formation is everywhere characterized by nodules or irregular bodies of black chert. The thickness of the Lenoir is about 125 feet.

It should be noted that the geologic map of this report (Pl. 1) is generalized and does not show the structural detail suggested by Butts as a result of more recent studies.

Since the post-Beekmantown Ordovician limestones in this area are different in lithologic character from the sections examined east of the Pulaski-Staunton fault, it is thought best not to attempt any definite correlation in this report. They will be referred to as undifferentiated Ordovician limestone.

The character and thickness of the rock comprising about the lower half of the Ordovician limestone belt near the southern end of Warm Springs Valley (Pl. 1, loc. 56) are given in the following section.

GEOLOGIC SECTION 36.—ON THE WEST SIDE OF U. S. HIGHWAY 220 ABOUT THREE-FIFTHS OF A MILE NORTHEAST OF FALLING SPRINGS CHURCH, ALLEGHANY COUNTY, VIRGINIA

	Thickness	
	Ft.	*In.*
Ordovician limestone, undifferentiated (lower 212 feet)		
30. Limestone, light-gray, compact; $CaCO_3$, 96.64; $MgCO_3$, 1.52; SiO_2, 1.00; Al_2O_3, 0.28; Fe_2O_3, 0.20; total, 99.64	104	0
29. Limestone, light-gray, compact, cherty	3	0
28. Limestone, light-gray, compact	48	0
Analysis of units 28 and 29, sampled thickness 51 feet: $CaCO_3$, 92.68; $MgCO_3$, 2.50; SiO_2, 3.40; Al_2O_3, 0.93; Fe_2O_3, 0.28; total, 99.79		
27. Limestone, thin-bedded, impure	10	0
26. Limestone, ribbon-bedded, impure; partly covered	4	6
25. Limestone, gray, compact	2	6
24. Covered interval	2	6
23. Limestone, clayey, crumbly-weathering	1	6
22. Limestone, gray, compact, laminated	4	0
21. Limestone, buff-colored, clayey	0	8
20. Limestone, light-gray, compact	5	0
19. Limestone, bluish-gray, striped	2	6
18. Dolomite siltstone	3	0
17. Limestone, buff-colored	1	6
16. Dolomite siltstone; contains chert fragments	2	0
15. Limestone, shaly	0	4
14. Dolomite siltstone	1	2
13. Limestone, bluish-gray, striped	1	0
12. Dolomite siltstone; smooth fracture	0	6

11. Limestone, bluish-gray, striped	1	6
10. Chert breccia	1	0
9. Limestone, bluish-gray, ribbon-bedded, impure	2	6
8. Shale, calcareous	1	6
7. Dolomite siltstone; weathers dingy-gray	3	4
6. Limestone, bluish-gray, clayey	1	2
5. Dolomite siltstone, bluish-gray; weathers brown	0	8
4. Limestone, bluish-gray, ribbon-bedded	1	0
3. Shale and thin-bedded limestone	1	6
2. Chert conglomerate	0	1
1. Limestone, bluish-gray, ribbon-bedded	0	8

Ordovician dolomite and limestone

The same belt of Ordovician limestone is partly exposed east and west of U. S. Highway 220 about 500 feet north of the Bath-Alleghany County line (Pl. 1, loc. 55). Here 60 feet of light-gray, compact limestone, exposed about 100 yards west of the highway, contains 97.31 percent calcium carbonate, 1.50 percent magnesium carbonate, and 0.25 percent silica. About 50 feet of impure limestone (Pl. 3C) representing the lower part of the Ordovician limestone belt is exposed along the east side of U. S. Highway 220 east of the above locality. A composite analysis of these beds shows 91.19 percent calcium carbonate, 2.50 percent magnesium carbonate, and 4.99 percent silica (Table 7).

The most northeasterly exposure of high-calcium limestone examined by the writer in Warm Springs Valley is in the village of Healing Springs (Pl. 1, loc. 54). Here an estimated thickness of 125 feet of light-gray, thick-bedded, compact limestone underlain by about 30 feet of thinner bedded, slightly impure limestone is exposed along U. S. Highway 220 and in the steep bluff to the west which rises about 60 feet above the highway.

Field studies indicate that there is at least 100 feet of limestone containing more than 97 percent calcium carbonate, that could be quarried at several localities (Pl. 1, loc. 54-57) in the southwestern part of Warm Springs Valley.

A large deposit of travertine or calcareous tufa occurs along Falling Spring Creek (Pl. 1, loc. 58) west of the water-gap through the southwestern end of Little Mountain. The deposit is not worked at the present time, but when visited in 1944, it was being quarried by the Falling Spring Lime Company. The workings consisted of shallow open-cuts in a small valley about 200 feet west of the base of the prominent waterfalls along the creek. Material recovered from these operations was hauled by narrow gauge railroad to the grinding plant at Falling Spring village, a distance of 2 miles. An analysis of a sample

of travertine dislodged from the old workings, a short distance north of U. S. Highway 220, shows 97.85 percent calcium carbonate, 0.90 percent magnesium carbonate, and 0.48 percent silica.

Rich Patch belt.—The Rich Patch belt of Ordovician limestone is exposed on the flanks of an anticlinal fold, the median part of which is occupied by Ordovician dolomite and limestone. Details of the stratigraphy in this area are given in a recent report by Lesure (1957). Several partial exposures of Ordovician limestones crop out along State Road 621 between Rich Patch Church and Hooks Mill.

The following section is generalized and represents a composite of three localities (Pl. 1, locs. 59-61) within one-half mile of Rich Patch Church.

GEOLOGIC SECTION 37.—ALONG STATE ROAD 621 BETWEEN RICH PATCH CHURCH AND HOOKS MILL, ALLEGHANY COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone	
Lincolnshire and Whistle Creek limestones (252 feet)	
7. Limestone, medium-grained, cherty; upper boundary uncertain	38
6. Limestone, dark-gray, medium-grained, very cherty	214
New Market limestone (176 feet)	
5. Limestone, pearl-gray, compact, thick-bedded; $CaCO_3$, 97.45; $MgCO_3$, 1.26; SiO_2, 0.40; Al_2O_3, 0.29; Fe_2O_3, 0.28; total, 99.68	20
4. Limestone, dark-gray, medium-grained, sparsely cherty	3
3. Limestone, pearl-gray, compact; a few chert bands	89
2. Limestone, pearl-gray, medium-grained; a few bands of nodular black chert	32
1. Covered interval; chert fragments in soil	32
Ordovician dolomite and limestone	

Light-gray, compact limestone, similar to unit 5 in the above section, was observed at several localities along the northeastern end of the Rich Patch belt of Ordovician limestone, but none of the localities examined appear to contain quarryable thicknesses of high-calcium limestone. Zones free of chert generally range from a few feet to a maximum of about 20 feet.

Iron Gate-Callaghan belt.—The Iron Gate-Callaghan belt of Upper Silurian and Lower Devonian limestone and sandstone, locally containing high-calcium limestone, is exposed at several localities along

or near the Chesapeake and Ohio Railway from the vicinity of Callaghan on the west to Iron Gate on the east. Covington, the county seat of Alleghany, and Clifton Forge are the principal towns.

The unit mapped (Pl. 1, unit G) as Upper Silurian and Lower Devonian limestone and sandstone includes the Ridgeley sandstone, Keyser limestone, and several formations comprising the Helderberg and Cayuga groups. The upper member of the Cayuga group, Tonoloway limestone, the Keyser limestone and the Coeymans, New Scotland, and Licking Creek limestones of the Helderberg group are the carbonate formations measured and sampled at a few localities in this part of the James River district. Additional sections and the details of the stratigraphy of these units, including a listing of diagnostic fossils for correlation, have been given by Swartz (1929, p. 27-75) and Butts (1940).

The character and thickness of the rocks comprising the Helderberg group along the eastern limb of the Iron Gate anticline southeast of Clifton Forge (Pl. 1, loc. 62) are given in the following section.

GEOLOGIC SECTION 38.—ALONG CHESAPEAKE AND OHIO RAILWAY AND U. S. HIGHWAY 220 ABOUT 1½ MILES SOUTHEAST OF CLIFTON FORGE, ALLEGHANY COUNTY, VIRGINIA

	Thickness Feet
Helderberg group: strike N. 55° E.; dip 45°-55° SE.	
Licking Creek limestone (108 feet)	
8. Covered interval	40±
7. Limestone, dark-gray, medium- to fine-grained, cherty; covered at the top	68
New Scotland formation (Healing Springs sandstone member)	
6. Sandstone, medium-gray, medium- to fine-grained. calcareous; a few thin beds of sandy limestone	16
Coeymans limestone	
5. Limestone, gray to pinkish-gray, medium-grained; $CaCO_3$, 95.74; $MgCO_3$, 2.10; SiO_2, 0.73; Al_2O_3, 0.31; Fe_2O_3, 0.60; total, 99.48	18
Keyser limestone (128 feet)	
Upper limestone member	
4. Limestone, gray, medium-grained, sandy; $CaCo_3$, 91.12; $MgCO_3$, 3.74; SiO_2, 3.55; Al_2O_3, 0.50; Fe_2O_3, 0.80; total, 99.71	34
Clifton Forge sandstone member	
3. Sandstone and thin shale partings; partly covered	63
Lower limestone member	
2. Covered interval	6
1. Limestone, dark-gray, nodular; covered at the base	25

Although exposures of the upper part of the Licking Creek limestone are not adequate for detailed measurement at this locality, it is assumed that about 40 feet of gray, medium-grained limestone, such as occurs along the strike on the north side of the river, may be represented in the covered interval.

The main constituents of the Helderberg group and the underlying Keyser (Pl. 4C) and Tonoloway limestones are well displayed in the eastern environs of Clifton Forge (Pl. 1, loc. 63).

GEOLOGIC SECTION 39.—ALONG NORTH SIDE OF CHESAPEAKE AND OHIO RAILWAY AND EAST OF U. S. HIGHWAY 220 BRIDGE IN CLIFTON FORGE, ALLEGHANY COUNTY, VIRGINIA

	Thickness Feet
Ridgeley sandstone	
15. Sandstone, coarse-grained, rusty-weathering; 6-inch layer of pebble conglomerate near base	18
Helderberg group	
Licking Creek limestone (100 feet)	
14. Limestone, light-gray, medium-grained; 1-foot chert zone at base	31
13. Limestone, light-gray, coarse-grained; 4-inch white chert bed at base	6
12. Limestone, gray, coarse-grained	5
11. Limestone, dark-gray, fine-grained, cherty	10
10. Limestone, massively-bedded, sparsely cherty	12
9. Limestone, drab-gray, very cherty; weathers to a mealy, spongy rock; section continued (units 1-8) on the west side of a small vertical fault	36
New Scotland formation (Healing Springs sandstone member)	
8. Sandstone, medium-grained	30
Coeymans limestone	
7. Limestone, gray, coarse-grained, impure	10
Keyser limestone (63 feet)	
Upper limestone member	
6. Limestone, dark-gray, fine- to medium-grained, impure	8
Clifton Forge sandstone member	
5. Sandstone, fine- to medium-grained; some layers cross-bedded; few shaly partings	55
Tonoloway limestone (upper 37 feet)	
4. Limestone, ochre-colored, shaly, partly decalcified; it is possible that this unit may belong with the overlying Keyser limestone	6
3. Limestone, straticulate, clayey	22
2. Sandstone, fine-grained	4
1. Limestone, straticulate; takes to crest of small anticline	5

Although no samples for analyses were collected here, it is reasonably certain that there are no thick units of high-calcium limestone. The most common impurity of these limestones, exclusive of the cherty layers, is the occurrence of disseminated rounded quartz grains which are usually well displayed on weathered surfaces. U. S. Highway 60, between Clifton Forge and Lowmoor, is on Devonian shale and sandstone, whereas farther westward the limestone belt because of gentle folding is repeated at several localities along the highway. One of the best exposures of the upper part of the Helderberg limestone is in the Lowmoor mine (Pl. 1, loc. 64), located along State Road 616 about half a mile southwest of Lowmoor village and about five miles southwest of Clifton Forge. The height of the mine, representing the upper part of the Licking Creek limestone, is estimated to be 50 feet (Pl. 7B). A composite sample of the limestone collected from the pillars and walls of the mine contained 93.31 percent calcium carbonate, 1.62 percent magnesium carbonate, and 3.89 percent silica.

The upper 50 feet of the Licking Creek limestone, representing the same beds mined at Lowmoor, crops out in a bluff along U. S. Highway 60 midway between Lowmoor and Island Ford (Pl. 1. loc. 65). An analysis of a composite sample, representing the full thickness of the limestone at this locality, shows 95.13 percent calcium carbonate, 1.24 percent magnesium carbonate, and 2.47 percent silica.

Due to gentle folding the Helderberg limestone is well exposed along U. S. Highway 60 at Jackson River bridge and along the Chesapeake and Ohio Railway about 200 yards southeast of the bridge. The following section was measured along the highway and in the bluff at the eastern end of the bridge (Pl. 1, loc. 66).

GEOLOGIC SECTION 40.—VICINITY OF JACKSON RIVER BRIDGE AT ISLAND FORD ABOUT 6 MILES SOUTHWEST OF CLIFTON FORGE, ALLEGHANY COUNTY, VIRGINIA

	Thickness Feet
Ridgeley sandstone: strike N. 50° E.; dip 50° SE.	
10. Sandstone, coarse-grained, rusty-weathering	12
Helderberg group	
Licking Creek limestone (170 feet)	
9. Limestone, light-gray, medium-grained; upper part sandy; $CaCO_3$, 92.30; $MgCO_3$, 1.18; SiO_2, 5.05; Al_2O_3, 0.11; Fe_2O_3, 0.80; total, 99.44	60
8. Limestone, dark-gray; contains a few stringers of light-colored chert in lower part	40
7. Limestone, dark-gray, very cherty	70

New Scotland formation (Healing Springs sandstone member)
6. Sandstone, gray, cross-bedded; contains sandy laminated limestone in the middle..... 24
5. Limestone, dark-gray, nodular..... 5
Coeymans limestone (24 feet)
4. Limestone, medium-gray 15
3. Limestone, pinkish, coarse-grained; few sandy streaks..... 9
Keyser limestone
Upper limestone member
2. Limestone, gray, impure..... 10
Analyses of units 2-4, sampled thickness 34 feet: $CaCO_3$, 80.58; $MgCO_3$, 2.35; SiO_2, 14.64; Al_2O_3, 0.70; Fe_2O_3, 1.16; total, 99.43.
Clifton Forge sandstone member
1. Sandstone, gray, cross-bedded; exposed in bed of Jackson River; thickness not determined.

The best grade limestone sampled in the Iron Gate-Callaghan belt crops out at Dunlap Beach (Pl. 1, loc. 67) about 2 miles southeast of Callaghan. Here about 45 feet of high-calcium limestone is well situated for small-scale quarrying. The following section begins within the lower part of the Licking Creek limestone and extends downward to include a few feet of the upper member of the Keyser limestone. It is of interest to note that the position of the lower member of the Licking Creek limestone with reference to the overlying Devonian shales is such that there is very little room for the upper part of the Licking Creek limestone and the Ridgeley sandstone which in a normal section occupy this interval.

GEOLOGIC SECTION 41.—ALONG STATE ROAD 600 AT DUNLAP BEACH ABOUT 2 MILES SOUTHEAST OF CALLAGHAN, ALLEGHANY COUNTY, VIRGINIA

	Thickness Feet
Helderberg group: strike N. 25° E.; dip 45° SE.	
Licking Creek limestone	
5. Limestone, dark-gray, cherty.....	27
New Scotland formation (Healing Springs sandstone member)	
4. Sandstone, medium-grained, cross-bedded.....	31
Coeymans limestone (55 feet)	
3. Limestone, medium-grained, sandy.....	10
2. Limestone, gray and pink, coarse-grained; $CaCO_3$, 96.45; $MgCO_3$, 1.00; SiO_2, 0.95; Al_2O_3, 0.14; Fe_2O_3, 0.92; total, 99.46	45
Keyser limestone	
Upper limestone member	
1. Limestone, dark-gray, medium-grained, sandy; coverd at base	24

The following section, illustrating the Helderberg sequence in the western part of the James River district (Pl. 1, loc. 70), has been taken from Butts (1940, p. 266-267), but modified to the extent that the Becraft and New Scotland limestones are designated Licking Creek limestone and the fossils listed by him for the various units are not included.

GEOLOGIC SECTION 42.—ALONG JACKSON RIVER ABOUT 1 MILE WEST OF KINCAID, ALLEGHANY COUNTY, VIRGINIA

	Thickness Feet
Helderberg group:	
Licking Creek limestone (200 feet)	
11. Limestone, very thick-bedded, coarse-grained, fragmental..	50
10. Limestone, argillaceous, knotty, cherty.....	150
New Scotland formation (Healing Springs sandstone member)	
9. Sandstone, thick-bedded, white, quartzitic; limy in lower part	55
Coeymans limestone (55 feet)	
8. Limestone, sandy	20
7. Limestone, thick-bedded, coarsely-crystalline, fragmental, some pinkish, resembles marble.....	35
Keyser limestone (176 feet)	
Upper limestone member	
6. Limestone, bluish, fine-grained; a few thin sandy layers....	22
Clifton Forge sandstone member	
5. Sandstone, cross-bedded, limy groundmass; more calcareous layers in middle.....	95
Lower limestone member	
4. Limestone, very nodular.....	5
3. Limestone, thick-bedded, partly sandy, partly finely crystalline, pink and gray above, basal 5 feet coarsely crystalline, 1-foot shale at base.....	54
Tonoloway limestone (upper 37 feet)	
2. Limestone, black	18
1. Limestone, black, laminated; takes to river level.....	19

The most westerly exposure of the Iron Gate-Callaghan belt of limestone noted by the writer is along State Road 600 about half a mile southeast of Callaghan (Pl. 1. loc. 68). Here about 50 feet of medium- to coarse-grained limestone representing the upper part of the Helderberg group contains 93.34 percent calcium carbonate, 1.45 percent magnesium carbonate, and 4.26 percent silica. These limestones and a part of the underlying cherty limestones are also displayed in a bluff, about 100 feet high, near the intersection of State Roads 600 and 662 (Pl. 1, loc. 69). In a small inactive quarry (Pl. 1. loc. 71) along

State Road 600 about 3 miles southwest of Falling Springs and at locality 72 about half a mile east of the quarry the upper part of the Licking Creek limestone contains abundant quartz sand. One analysis of a sample representing about 30 feet of limestone in the quarry shows 85.60 percent calcium carbonate, 0.87 percent magnesium carbonate, and 11.39 percent silica.

Marble Valley-Goshen belt.—The Marble Valley-Goshen belt of the Upper Silurian and Lower Devonian limestone and sandstone is partly exposed at several localities along the west limb of the Elliott Knob syncline (Pl. 1).

The character and thickness of the limestones exposed along a tributary to Calfpasture River near Marble Valley (Pl. 1, loc. 73) are given in the following section.

GEOLOGIC SECTION 43.—ALONG CLAYTONS MILL CREEK NEAR MARBLE VALLEY ABOUT 4½ MILES SOUTHWEST OF DEERFIELD, AUGUSTA COUNTY, VIRGINIA

	Thickness *Feet*
Helderberg group: strike N. 22° E.; dip 42° SE.	
8. Limestone, light-gray, medium-grained	50
7. Limestone, dark bluish-gray, cherty	50
6. Limestone, light-gray, coarse-grained; $CaCO_3$, 97.86; $MgCO_3$, 0.97; SiO_2, 0.23; Al_2O_3, 0.20; Fe_2O_3, 0.34; total, 99.60	60
5. Limestone with sandy streaks, crinkly-weathering	11
4. Limestone, dark-gray, nodular-weathering	6
3. Limestone, dark-gray, fine-grained; contains light-gray chert	
2. Limestone, light-gray, coarse-grained	25
Keyser limestone	
1. Limestone, dark-gray, cherty, cobbly-weathering; thickness estimated	50

Helderberg limestone, such as described in Sections 43 and 44, was noted at several localities in Marble Valley, but the field studies were not adequate for the separation of distinct members. For example, unit 6 is Coeymans lithology; however, this layer is underlain by sandstone and cherty limestone which resemble the New Scotland formation. On the basis of lithologic character, it is the writer's opinion that unit 6 is a coarse-grained facies of the Licking Creek limestone and unit 2 may represent the true Coeymans.

About 80 feet of light-gray, coarse-grained limestone (Licking Creek [?] limestone) is exposed along the trail leading to the fire tower of Sideling Hill about one-fourth of a mile west of State Road

600 and 5 miles north of Goshen (Pl. 1, loc. 74). Farther southwestward along the strike there are continuous exposures along State Road 600 and Calfpasture River for a distance of about 1,000 feet. The character and thickness of the rocks at this locality (Pl. 1. loc. 75) are given in the following section.

GEOLOGIC SECTION 44.—ALONG CALFPASTURE RIVER AT THE SOUTHEAST BASE OF SIDELING HILL ABOUT 4 MILES NORTH OF GOSHEN, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Ridgeley sandstone	
9. Sandstone, medium-grained	18
Helderberg group: strike N. 38° E.; dip 38° SE.	
8. Limestone, light-gray, medium-grained; $CaCO_3$, 93.67; $MgCO_3$, 1.64; SiO_2, 2.83; Al_2O_3, 0.43; Fe_2O_3, 0.94; total, 99.51	38+
7. Limestone, dark-gray, cherty	40
6. Limestone, gray and pink, medium-grained; $CaCO_3$, 95.44; $MgCO_3$, 1.92; SiO_2, 1.30; Al_2O_3, 0.48; Fe_2O_3, 0.38; total, 99.52	39
5. Limestone, gray and pink, medium-grained, sandy	15
4. Limestone, dark-gray, fine-grained, cherty	34
3. Limestone, gray and pink, medium-grained	14
2. Sandstone, fine- to medium-grained, limy; contains 1-foot bed of shaly limestone near middle	10
1. Limestone, fine-grained; a few thin beds of coarse-grained limestone; covered at the base; $CaCO_3$, 92.91; $MgCO_3$, 1.50; SiO_2, 3.57; Al_2O_3, 1.28; Fe_2O_3, 0.70; total, 99.96	7

This belt of carbonate rocks is split into two prongs by an anticlinal area of massive Silurian sandstone, forming Mill Mountain, about 3 miles northeast of Panther Gap. Southwestward these bands border the Silurian sandstone on both sides to a point east of Iron Gate where they combine and plunge beneath the overlying Devonian shale and sandstone. A good exposure of the upper part of the limestones comprising the westernmost belt referred to above is along the Chesapeake and Ohio Railway and in an inactive quarry (Pl. 1. loc. 76) along State Highway 501 about half a mile west of Panther Gap.

GEOLOGIC SECTION 45.—INACTIVE QUARRY ALONG STATE HIGHWAY 501 ABOUT 3 MILES NORTHWEST OF GOSHEN, BATH COUNTY, VIRGINIA

	Thickness Feet
Ridgeley sandstone	
6. Sandstone, medium-grained	39

Helderberg group: strike N. 30° E.; dip 50° SE.
Licking Creek limestone (115 feet)

5. Limestone, gray, medium-grained; upper 10 feet sandy limestone; $CaCO_3$, 92.71; $MgCO_3$, 0.92; SiO_2, 5.04; Al_2O_3, 0.45; Fe_2O_3, 0.46; total, 99.58	55
4. Limestone, gray, medium-grained, sparsely cherty	12
3. Limestone, dark-gray, fine- to medium-grained, very cherty	48
New Scotland (?) limestone	
2. Limestone, gray, medium-grained	10
Coeymans limestone	
1. Limestone, medium-gray, mostly coarse-grained, thick-bedded; 10 foot bed of pink limestone about 30 feet below top; covered at the base	50
Analysis of units 1 and 2, sampled thickness 60 feet: $CaCO_3$, 92.88; $MgCO_3$, 1.98; SiO_2, 3.75; Al_2O_3, 0.60; Fe_2O_3, 0.76; total, 99.97.	

An elongate anticline with Devonian and Silurian limestone and sandstone occupying the crest of the fold extends from a locality 3 miles southwest of Millboro Springs southwestward for approximately 4 miles. There are excellent exposures of bedrock, although displaying minor folding and faulting, along State Highway 42 near the southwestern end of this belt (Pl. 1, loc. 77). Here massively bedded coarse-grained limestone (Pl. 7A) has been extensively quarried and used as road ballast. A composite section of the Helderberg and Keyser limestones made from exposures in the roadside quarry (units 1-9) and along Highway 42 about 1,000 feet to the west (units 10-19) are given in the following section.

GEOLOGIC SECTION 46.—ALONG STATE HIGHWAY 42 ABOUT 7 MILES SOUTHWEST OF MILLBORO SPRINGS, BATH COUNTY, VIRGINIA

	Thickness Feet
Ridgeley sandstone	
19. Sandstone, medium-grained; weathers brownish	15
Helderberg group: strike N. 30° E.; dip 70° NW. (units 10-19); 10°-20° SE. (units 1-9)	
Licking Creek limestone (145 feet)	
18. Limestone, medium-gray, medium- to coarse-grained; upper 5 feet sandy	75
17. Limestone, gray, medium-grained; thin chert stringer at top	12
16. Limestone, gray, medium-grained; 8-inch chert layer at top	4
Analysis of units 16-18, sampled thickness 91 feet: $CaCO_3$, 93.83; $MgCO_3$, 1.15; SiO_2, 4.08; Al_2O_3, 0.40; Fe_2O_3, 0.48; total, 99.93.	

15. Limestone, dark-gray, fine-grained, very cherty	17
14. Limestone, gray, coarse-grained	5
13. Limestone, dark bluish-gray, cherty; thin clay bed at top	32
New Scotland (?) limestone (25 feet)	
12. Limestone, medium-grained; contains abundant sand grains and sandy streak	7
11. Sandstone, calcareous (Healing Springs [?] sandstone member)	15
10. Limestone, light-gray; grades upward into calcareous sandstone; faulted at base	3
Coeymans limestone	
9. Limestone, gray and pink, coarse-grained	12-15
Keyser limestone (118 feet)	
Clifton Forge sandstone member	
8. Sandstone, gray, calcareous	20
7. Limestone, dark-gray, fine-grained, cherty	15
6. Shale, dark, contorted	1
5. Sandstone, medium-bedded	12
4. Sandstone, shaly	10
3. Sandstone, massively-bedded	10
Lower limestone member	
2. Limestone, mainly light-gray with pink layers, medium- to coarse-grained; $CaCO_3$, 91.60; $MgCO_3$, 2.48; SiO_2, 4.61; Al_2O_3, 0.70; Fe_2O_3, 0.60; total, 99.99	50
Tonoloway limestone (upper part exposed along crest of anticline)	
1. Limestone, dark bluish-gray, fine-grained, platy; shows columnar jointing (Pl. 3A)	32

Fordwick-Bells Valley belt.—This belt of Upper Silurian and Lower Devonian limestone and sandstone begins about 5 miles northeast of Fordwick and continues southwestward to Goshen, closely paralleling the Chesapeake and Ohio Railway. The Fordwick plant of the Lehigh Cement Company operates a large limestone quarry in this belt at a locality (Pl. 1, loc. 79) about one mile south of Craigsville. Devonian shale used as a part of the mixture for the manufacture of Portland cement by this company is obtained from a quarry located near State Highway 42 about three-fourths of a mile northeast of Craigsville.

The general character of the rocks comprising the Fordwick-Bells Valley belt in the vicinity of Craigsville is given in the following section (Pl. 1, loc. 78).

GEOLOGIC SECTION 47.—INACTIVE QUARRY ALONG STATE ROAD 684 ABOUT ONE-FOURTH OF A MILE EAST OF CRAIGSVILLE, AUGUSTA COUNTY, VIRGINIA

	Thickness Feet
Helderberg group: strike N. 65° E.; dip 35° NW.	
Licking Creek limestone (80 feet)	
10. Limestone, gray, medium-grained; a few shaly beds near base; partly covered	35
9. Limestone, dark-gray, fine- to medium-grained; black chert abundant in lower part	45
New Scotland (?) limestone	
8. Limestone, light-gray, coarse-grained; four feet of impure beds at top	20
Coeymans limestone	
7. Limestone, light-gray to pink, coarse-grained (Pl. 6C)	40
Keyser limestone	
6. Limestone, gray, medium-grained, nodular; a few shaly partings	22
5. Limestone, gray, coarse-grained	14
4. Limestone, dark-gray, fine-grained, sandy; weathers dark-brown to drab-gray	18
3. Limestone, coarse-grained; a few clayey streaks and thin intercalations of fine-grained limestone	10
2. Limestone, light-gray to pink, coarse-grained	35
1. Sandstone; thickness undetermined.	

It is estimated that approximately 300 feet of the unit mapped as Upper Silurian and Lower Devonian limestone and sandstone is exposed locally along the southeast slope of Black Oak Ridge between Craigsville and Bells Valley. One of the best exposures of the Helderberg and upper Keyser limestone noted in this area is along State Road 683 about two miles southwest of Craigsville (Pl. 1, loc. 80).

GEOLOGIC SECTION 48.—ALONG STATE ROAD 683 ABOUT 2 MILES SOUTHWEST OF CRAIGSVILLE, AUGUSTA COUNTY, VIRGINIA

	Thickness Feet
Ridgeley sandstone	
11. Sandstone, brownish-weathering, medium-grained, friable	12
Helderberg group: strike N. 40° E.; dip 25°-40° SE.'	
Licking Creek limestone (125 feet)	
10. Limestone, gray, medium-grained	55
9. Covered interval	30
8. Limestone, dark-gray, fine-grained, cherty	40
New Scotland limestone	
7. Limestone, gray, medium-grained; contains diagnostic fossils of the New Scotland	10±

Coeymans limestone

6. Limestone, gray and pink, coarse-grained..... 44
   Analysis of units 6 and 7, sampled thickness 54 feet: $CaCO_3$, 96.64; $MgCO_3$, 1.56; SiO_2, 0.58; Al_2O_3, 0.69; Fe_2O_3, 0.04; total, 99.51.

Keyser limestone

5. Limestone, dark-gray, nodular; a few shaly partings..... 18
4. Limestone, dark-gray, nodular; a few coarse stringers..... 11
3. Covered interval 15
2. Limestone, light-gray, coarse-grained..... 41
1. Largely covered; a few exposures of limestone, shaly limestone, and shale; thickness undetermined.

The following section is a composite of exposures just north of State Road 614 and in an inactive quarry one-fourth of a mile southeast of Bells Valley (Pl. 1, loc. 81). The lithology and thickness of the units of the Keyser limestone (units 1-11) and the recognition of diagnostic fossils which identify the New Scotland limestone are taken from a section published by Swartz (1929, p. 66-67).

GEOLOGIC SECTION 49.—ALONG STATE ROAD 614 AND IN THE VICINITY OF AN INACTIVE QUARRY ONE-FOURTH OF A MILE SOUTHEAST OF BELLS VALLEY, ROCKBRIDGE COUNTY, VIRGINIA

Thickness
Feet

Helderberg group: strike N. 40° E.; dip 55° NW.

Licking Creek limestone (129 feet)

16. Covered interval 45
15. Limestone, gray, medium-grained, sparsely cherty..... 31
14. Limestone, dark-gray, fine- to medium-grained, cherty..... 53

New Scotland limestone

13. Limestone, gray, coarse-grained; contains characteristic New Scotland fossils (Swartz, 1929, p. 66)..... 15

Coeymans limestone

12. Limestone, gray and pink, coarse-grained; a few impure crinkly bands 46
    Analysis of units 12 and 13, sampled thickness 61 feet: $CaCO_3$, 96.65; $MgCO_3$, 1.27; SiO_2, 0.95; Al_2O_3, 0.62; Fe_2O_3, 0.20; total, 99.69 .....

Keyser limestone

11. Thin-bedded shale and limestone; the upper surface is extensively ripple marked..... 6
10. Thick-bedded crystalline limestone..... 7
9. Thin-bedded shaly limestone..... 3
8. Massive fine-grained limestone, weathering greenish..... 42

7. Thick-bedded hard gray sandstone, weathered buff to white, forming the backbone of the knoll. Like the underlying sandstones, this is a tongue of the Clifton Forge sandstone member of the Keyser	4
6. Thin-bedded yellowish-green, somewhat arenaceous shale (tongue of the Big Mountain [?] shale member)	9½
5. Medium-bedded gray sandstone (tongue of the Clifton Forge sandstone member)	4½
4. Dark-grayish soft shale, mostly concealed	8
3. Calcareous sandstone, weathered buff (tongue of the Clifton Forge sandstone member)	6
2. Thick-bedded, somewhat crystalline limestone	10
1. Concealed. Some arenaceous shale toward top. Keyser (?)	34

Tonoloway limestone

It is the writer's opinion that, locally, the belts mapped as Upper Silurian and Lower Devonian limestone and sandstone in the western part of the James River district may contain units of sufficient thickness and purity to warrant small-scale operations for the production of high-calcium limestone. Additional field study and testing is recommended at those localities cited which show a minimum of 30 to 40 feet of limestone containing around 95 to 96 percent calcium carbonate.

High-Magnesium Dolomite

Cambrian dolomite (Shady-Tomstown dolomite) in the James River district is composed largely of high-magnesium dolomite as defined in this report. Natural outcrops of Cambrian dolomite occur in the vicinity of Natural Bridge Station and southwestward along the western foothills of the Blue Ridge at several localities east of Indian Rock, Buchanan, and Lithia (Pl. 1, unit A). Cambrian dolomite was not observed north of the general latitude of Glasgow. Notwithstanding this restricted distribution, there are several large potential quarry sites in the southeastern part of the district. Because of the poor exposures and faulting, no accurate determination of the thickness could be made. The best estimates of thickness, based upon several incomplete exposures, show from about 1,300 to 1,600 feet, in the vicinity of Natural Bridge Station.

The geology of the belt of high-magnesium dolomite south of the latitude of Buena Vista, including the structural interpretation of Sallings Mountain and the boundary of the noncarbonate rocks to the southeast, is from manuscript geologic maps made by R. O. Bloomer for the Virginia Geological Survey.

The character and thickness of the rocks near the northeastern end of the exposed part of the high-magnesium dolomite belt (Pl. 1, loc. 82) are given in the following section.

GEOLOGIC SECTION 50.—VICINITY OF NATURAL BRIDGE STATION ABOUT 100 YARDS NORTHEAST OF STATE HIGHWAY 249 AND WEST OF STATE ROAD 688, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Cambrian dolomite: strike N. 59° E.; dip, overturned, 80° SE.	
Shady dolomite (1210+ feet)	
10. Dolomite, dark bluish-gray, medium-grained; probably faulted at top	243
9. Dolomite, medium- to light bluish-gray, fine-grained	55
Analysis of units 9 and 10, sampled thickness 298 feet: $CaCO_3$, 54.16; $MgCO_3$, 42.01; SiO_2, 3.48; Al_2O_3, 0.24; Fe_2O_3, 0.48; total, 100.37	
8. Shale, brownish-gray	2
7. Dolomite, flesh-colored to white, medium-grained; a few disseminated grains of quartz sand in basal bed	251
6. Dolomite, light-gray, medium-grained	268
Analysis of units 6 and 7, sampled thickness 519 feet: $CaCO_3$, 54.56; $MgCO_3$, 42.98; SiO_2, 1.44; Al_2O_3, 0.48; Fe_2O_3, 0.40; P_2O_5, 0.01; Na_2O, 0.054; K_2O, 0.047; total, 99.97	
5. Dolomite, dark bluish-gray, medium- to fine-grained; abundant veins and vugs of white carbonate minerals	194
4. Dolomite, flesh-colored, medium-grained; sugary texture	7
3. Dolomite, light- to bluish-gray; abundant veins and vugs of white carbonate minerals	90
2. Dolomite, light-gray and flesh-colored mottled; sugary texture	49
1. Dolomite, light flesh-colored, medium-grained; takes to near top of underlying quartzite along State Road 688	51
Analysis of units 1-5, sampled thickness 391 feet: $CaCO_3$, 55.98; $MgCO_3$, 42.05; SiO_2, 1.00; Al_2O_3, 0.24; Fe_2O_3, 1.08; total, 100.35	
Cambrian basal clastics	

A part of the high-magnesium dolomite belt described above forms a conspicuous bluff along the north side of James River east and west of the crossing of the Norfolk and Western and the Chesapeake and Ohio railways at Natural Bridge Station (Pl. 1, loc. 83). It is thought that some repetition of the dolomite by folding is present here, since the underlying Cambrian quartzite, cropping out along the axis of an anticline, was observed at least as far southwestward as State Highway 249, less than one-fourth of a mile north of James River.

The character and composition of approximately 600 feet of dolomite, perhaps occurring within the lower part of the Cambrian dolomite unit at Natural Bridge Station, are given in the following section.

GEOLOGIC SECTION 51.—ALONG CHESAPEAKE AND OHIO RAILWAY AT NATURAL BRIDGE STATION, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Cambrian dolomite: strike N. 60° E.; dip 45° SE.	
Shady dolomite (within lower part, 603 feet)	
4. Dolomite, light cream-colored, medium-grained	65
3. Dolomite, light-gray, medium-grained	171
2. Dolomite, light cream-colored, medium-grained	247
1. Dolomite, gray, fine- to medium-grained	120
Analysis of units 1-4, sampled thickness 603 feet: $CaCO_3$, 54.30; $MgCO_3$, 43.91; SiO_2, 1.15; Al_2O_3, 0.53; Fe_2O_3, 0.38; Na_2O, 0.10; K_2O, 0.03; total, 100.40	

The following geologic section includes the middle and upper parts of the belt of high-magnesium dolomite and the lower part of the overlying unit of Cambrian dolomite and limestone. The section begins on the east at James River about one-fourth of a mile southwest of Natural Bridge Station and extends northwestward to a point near the junction of State Road 1001 and State Highway 249 (Pl. 1, loc. 84).

GEOLOGIC SECTION 52.—ALONG STATE ROAD 1001 AND TRIBUTARY TO JAMES RIVER ABOUT ONE-FOURTH OF A MILE WEST OF NATURAL BRIDGE STATION, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Cambrian dolomite and limestone: strike N. 48° E.; dip, overturned, 85° SE.	
Waynesboro formation (lower 423 feet)	
9. Dolomite, dark bluish-gray, fine-grained; a few thin shale partings	125
8. Dolomite, dark-gray to brownish-gray, fine-grained; a few shaly beds; lower boundary uncertain	298
Cambrian dolomite	
Shady dolomite (middle and upper, 1067 feet)	
7. Dolomite, light-gray, fine-grained	112
Analysis of units 7-9, sampled thickness 535 feet: $CaCO_3$, 52.37; $MgCO_3$, 40.90; SiO_2, 4.84; Al_2O_3, 1.58; Fe_2O_3, 0.78; total, 100.47.	

6. Dolomite, gray to cream-colored, medium-grained.....	85
5. Largely covered; a few beds of light-gray dolomite.....	199±
4. Dolomite, cream-colored, medium-grained.....	128
3. Dolomite, light-gray, fine-grained.....	82
2. Dolomite, gray, medium-grained; in part banded and fractured	249
1. Dolomite, dark-gray, fine- to medium-grained.....	212
Analysis of units 1-5, 6 sampled thickness 756± feet: $CaCO_3$, 58.17; $MgCO_3$, 40.20; SiO_2, 1.00; Al_2O_3, 0.25; Fe_2O_3, 0.58; total, 100.20.	

Since unit 1 of the above section closely overlies unit 4 of Geologic Section 51, it is thought that the total thickness of high-magnesium dolomite exposed in this area is approximately 1670 feet. All of the analyses show more than 40 percent magnesium carbonate and one sampled unit of about 600 feet (Geologic Section 51) contained 43.91 percent magnesium carbonate and 1.15 percent silica.

About 50 feet of high-magnesium dolomite is exposed in a small abandoned quarry along the Chesapeake and Ohio Railway half a mile southwest of Natural Bridge Station. At this locality the Shady dolomite strikes in a northwesterly direction and is nearly in contact with red shale and impure dolomite which crop out at several places along the railroad southwest to the Rockbridge-Botetourt County line. The only other exposure of high-magnesium dolomite north of the County line which may represent a part of the Cambrian dolomite belt is along the Norfolk and Western Railway about 1¼ miles east of Gilmore Mills (Pl. 1, loc. 85). Here light- and dark-gray dolomite is exposed in a bluff for a distance of 300 feet. Farther southwestward, about 1 mile south of Gilmore Mills, red shales crop out within 400 feet of Cambrian quartzite, thus the Shady, if represented in the covered interval, is relatively thin.

An estimated 150 feet of typical cream-colored high-magnesium dolomite is exposed in a small abandoned quarry (Pl. 1, loc. 86) along the Chesapeake and Ohio Railway about three-fourths of a mile south of Rocky Point. The rocks sampled at this locality are of exceptional purity, containing 55.89 percent calcium carbonate, 43.41 percent magnesium carbonate, and 0.20 percent silica (Table 7).

Approximately 800 feet of dolomite, probably including the upper part of the Cambrian dolomite and the lower part of the overlying mapped unit, crop out along the Norfolk and Western Railway at locality 87, about 2 miles northeast of Buchanan. Faulting is indicated here since Cambrian quartzite on the east is within 200 or 300 feet of the belt mapped as Cambrian dolomite and limestone on the west. The

thickness and chemical composition of the rocks which are fully exposed at this locality are given in the following section.

GEOLOGIC SECTION 53.—ALONG NORFOLK AND WESTERN RAILWAY ABOUT 2 MILES NORTHEAST OF BUCHANAN. BOTETOURT COUNTY, VIRGINIA

	Thickness Feet
Cambrian dolomite and limestone: strike N. 42° E.; dip 60° NW.	
Waynesboro formation (lower 642 feet)	
3. Dolomite, dark bluish-gray, fine-grained, impure; $CaCO_3$, 51.03; $MgCO_3$, 39.06; SiO_2, 9.04; Al_2O_3, 0.72; Fe_2O_3, 0.56; total, 100.41	530
2. Dolomite, medium-gray, fine-grained, impure; structure uncertain; probably faulted at the base; $CaCO_3$, 51.23; $MgCO_3$, 36.98; SiO_2, 10.28; Al_2O_3, 0.80; Fe_2O_3, 0.88; total, 100.17	112
Cambrian dolomite: strike N. 15° E.; dip, overturned, 45° SE.	
Shady dolomite (upper 155 feet)	
1. Dolomite, light-gray to cream-colored, medium-grained; covered at the base; $CaCO_3$, 52.02; $MgCO_3$, 39.83; SiO_2, 7.52; Al_2O_3, 0.48; Fe_2O_3, 0.36; total, 100.21	155

Since unit 1 in the above section contains less than 40 percent magnesium carbonate and more than 4 percent silica, it does not meet the specification of high-magnesium dolomite as defined in this report. The lithology of this rock does not appear to be different from any of the high-magnesium dolomite units sampled throughout the James River district.

One of the best natural exposures of a part of the Cambrian dolomite is about 1½ miles northeast of Buchanan and less than 500 feet northeast of the James River Hydrate and Supply Company quarry (Pl. 1, loc. 88). Here about 800 feet of gray- to cream-colored dolomite, striking N. 40° E., and dipping overturned 80° SE., is almost fully exposed along a small tributary to James River. The rocks partly exposed west of the belt of high-magnesium dolomite included about 800 feet of dark-gray dolomite with minor amounts of silty and shaly beds.

GEOLOGIC SECTION 54.—ABOUT 500 FEET NORTHEAST OF THE JAMES RIVER HYDRATE AND SUPPLY COMPANY QUARRY AND 1½ MILES NORTHEAST OF BUCHANAN, BOTETOURT COUNTY, VIRGINIA

	Thickness Feet
Cambrian dolomite and limestone: strike N. 40° E.; dip, overturned, 80° SE.	
Waynesboro formation (lower 713 feet)	
10. Dolomite, dark bluish-gray, silty; a few red and brown shale beds	294

9. Mostly covered; a few beds of dolomite	328
8. Dolomite, bluish-gray, fine-grained	61
7. Shale, olive drab-colored; a few beds of light-gray dolomite	30
Cambrian dolomite	
Shady dolomite (upper 821 feet)	
6. Dolomite, white to cream-colored, medium-grained	90
5. Covered interval	55
4. Dolomite, white to cream-colored, medium-grained; a few thin covered intervals	530
3. Dolomite, light-gray, medium-grained	60
2. Dolomite, gray- to cream-colored, medium-grained	8
Analysis of units 2-4, 6, sampled thickness 688 feet: $CaCO_3$, 54.51; $MgCO_3$, 43.65; SiO_2, 1.03; Al_2O_3, 0.41; Fe_2O_3, 0.38; K_2O, 0.03; Na_2O, 0.12; total, 100.13	
1. Dolomite, light-gray, fine-grained	78

The James River Hydrate and Supply Company quarry and plant (Pl. 1, loc. 89) are along James River and the Norfolk and Western Railway about 1½ miles northeast of Buchanan. When visited in 1956 the quarry was approximately 450 feet wide, and 100 feet deep along the eastern side. Quarry operations are limited on the southwest by James River, but the belt of dolomite now being quarried can be followed along the strike in a northeasterly direction. Although the rocks were not sampled in the quarry, it is reasonable to assume a similar chemical composition to those described in Geologic Section 54, less than 500 feet northeast of the present operations.

From locality 89 southwestward to the Liberty Limestone Corporation quarry and plant (Pl. 1, loc. 90) a distance of approximately half a mile, the belt of Cambrian dolomite is largely concealed by James River. In the Liberty Limestone Corporation quarry, which is approximately 1000 feet long and 300 wide, the Cambrian dolomite strikes N. 40° E. and dips, overturned, 60° SE. The southwestern rim of the quarry is approximately 500 feet above James River, thus it represents the highest quarry face in the James River district. Cambrian quartzite, which is faulted upon the dolomite, crops out at the southeastern edge of the quarry and in the ridge above the quarry face on the southeast side. Dolomite along the western side of the quarry is closely overlain, in normal geologic sequence, by impure dolomite and shale of Cambrian age. One sample of ground dolomite from the storage bin analyzed 42.98 percent magnesium carbonate, 55.87 percent calcium carbonate, and 0.35 percent silica (Table 7).

Approximately 500 feet of gray- to cream-colored Cambrian dolomite is exposed along a small stream paralleling State Highway 43

about three-fourths of a mile southeast of Buchanan (Pl. 1, loc. 91) and one-fourth of a mile southwest of the Liberty Limestone Corporation quarry.

The best natural exposure of dolomite observed in the southern part of the James River district is at locality 92 about 1 mile south of Buchanan.

GEOLOGIC SECTION 55.—ABOUT HALF A MILE EAST OF THE NORFOLK AND WESTERN RAILWAY AND 1 MILE SOUTH OF BUCHANAN, BOTETOURT COUNTY, VIRGINIA

	Thickness Feet
Cambrian dolomite: strike N. 55° E.; dip, overturned, 75° SE.	
Shady dolomite (upper 731 feet)	
2. Dolomite, light- to medium-gray, fine- to medium-grained; $CaCO_3$, 54.60; $MgCO_3$, 41.08; SiO_2, 3.50; Al_2O_3, 0.18; Fe_2O_3, 0.64; P_2O_5, 0.02; total 100.02	336
1. Dolomite, light-gray to cream-colored, fine- to medium-grained; $CaCO_3$, 54.80; $MgCO_3$, 40.02; SiO_2, 4.48; Al_2O_3, 0.28; Fe_2O_3, 0.36; P_2O_5, 0.019; total 99.95	395

The time available for field work was not sufficient to work out the details of structure at the above locality, particularly the relation of the Cambrian quartzite to the Cambrian dolomite. A small cross fault offsets the upper part of the quartzite formation at the eastern end of Geologic Section 55, but such minor structures could not be shown on the geologic map (Pl. 1). It is also possible that since there is only 730 feet of high-magnesium dolomite exposed at this locality, or about half of the estimated thickness of the vicinity of Natural Bridge Station, the lower part of the Shady has been covered by overthrust Cambrian quartzites. Such a fault is shown at the eastern side of the Liberty Limestone Corporation quarry (Pl. 1, loc. 90) about a mile northeastward along the strike of the same belt.

Approximately 100 feet of light-gray Cambrian dolomite is exposed in an inactive quarry (Pl. 1, loc. 93) along State Road 625 about 1 mile southeast of the Norfolk and Western Railway and 2 miles southwest of Buchanan. The northeastern face of this quarry is estimated to be 100 feet high and the floor slightly above the level of Laurel Run on the southwest. One notable feature of this operation is the thin mantle rock and the apparent absence of clayey streaks and solution cavities. Farther southwestward the belt of high-magnesium dolomite is partly exposed where it wraps around the end of an anticline plunging gently southwestward. The width of the outcrop belt

at this locality (Pl. 1, loc. 94) is about 500 feet and the dolomites are overlain in normal geologic sequence by characteristic red shales of the overlying mapped unit (Pl. 1). This site is recommended for detailed study and test drilling.

The most southerly exposure of a part of the Cambrian dolomite belt in the James River district is near State Road 645 about 5 miles southwest of Buchanan and 2 miles east of Lithia (Pl. 1, loc. 95). At this locality the belt containing high-magnesium dolomite, although poorly exposed, is estimated to be 650 feet wide. An analysis of a sample representing about 125 feet of light-gray medium-grained dolomite near the top of the mapped unit shows 54.60 percent calcium carbonate, 42.79 percent magnesium carbonate, and 2.04 percent silica (Table 7).

The principal belt of Cambrian dolomite along the western foothills of the Blue Ridge is mapped as extending in a southwesterly direction through the northern part of Arnold's Valley to a cross fault about 3 miles south of Natural Bridge Station. This belt of dolomite, except for scattered exposures near the southwestern end, is largely covered. Sampled units of dolomite cropping out within an area estimated at one acre at locality 96 contain 43.24 percent magnesium carbonate, and less than one percent silica.

Impure Limestone

Since the noncarbonate constituents are important for certain uses, the heading impure limestone is used in this report to describe those rock units composed largely of limestone which are commonly low in magnesium carbonate and contain more than five percent noncarbonates. These noncarbonates, or impurities, include chiefly silica, alumina, and iron oxide.

Impure limestones, exclusive of the high-calcium units, comprise a part of the belts mapped as Ordovician limestone, Ordovician limestone and shale, and Upper Silurian and Lower Devonian limestone and sandstone. (Pl. 1). Older mapped units also contain variable amounts of impure limestone, but they are treated under the heading of "dolomite and limestone."

Ordovician limestone.—The general character and thickness of the rocks comprising the belts mapped as Ordovician limestone are included under the discussion of high-calcium limestone (Geologic Sections 1-37). In some of these sections the full thickness is impure limestone; whereas in others, impure units of variable thickness are asso-

ciated with high-grade limestone. Many impure zones, ranging in thickness from a few feet to more than 100 feet in the southern part of Shenandoah Valley contain from about 88 to 92 percent calcium carbonate, one to three percent magnesium carbonate, and from five to seven percent silica. A much higher content of silica could be obtained locally by sampling only the cherty or shaly beds.

Ordovician limestone and shale.—The belt mapped (Pl. 1) as Ordovician limestone and shale (Edinburg and Collierstown), overlying the belt of Ordovician limestone, is composed of varying proportions of impure black fine-grained limestone and shale. According to Campbell, the succession of dark-blue limestone, argillaceous limestone, and calcareous shale, which he named Liberty Hall limestone, in the Lexington area is about 1,000 feet thick. A few analyses of samples collected by Bassler (1909, p. 128, 129, 131) from various horizons within this unit of impure limestone at several localities in the southern part of Shenandoah Valley are given in Table 6.

TABLE 6.—ANALYSES OF LIBERTY HALL LIMESTONE, ROCKBRIDGE COUNTY, VIRGINIA

(Nos. 1, 5, and 6 analyzed by J. H. Gibboney; Nos. 2-4, 7-10 analyzed by Wm. M. Thornton.)

	I	II	III	IV	V	VI	VII	VIII	IX	X
SiO_2	10.24	12.42	12.29	10.97	30.24	17.86	8.09	11.03	1.67	7.99
Al_2O_3, Fe_2O_3	0.74	4.26	3.54	4.44	4.56	1.60	3.30	1.97	1.40	2.72
$CaCO_3$	86.00	80.31	78.73	80.80	58.93	73.62	81.68	83.92	90.87	85.05
$MgCO_3$	2.10	2.26	4.61	1.76	5.81	6.38	4.85	3.33	5.24	3.79
Total	99.08	99.25	99.17	97.97	99.54	99.46	97.92	100.15	99.18	99.55

I. Spring Cave Hill, Lexington, Virginia.
II-IV. Along Chesapeake and Ohio Railway, two miles east of Lexington, Virginia.
V. Kerrs Creek, Virginia.
VI. About five miles west of Rockbridge Baths, Virginia.
VII-X. Vicinity of Murat Post Office, Virginia.

Ordovician limestone and shale is well exposed at many localities in Augusta, Rockbridge, and eastern Botetourt counties, but, due to repetition by close folds (Pl. 6A), it is difficult to arrive at anything more than a reasonable estimate of the thickness of the rocks. One of

the best exposures of the Ordovician limestone and shale belt, with a thickness of approximately 800 feet, is along Colliers Creek about two and one-half miles southeast of Collierstown Post Office (Pl. 1, loc. 22).

GEOLOGIC SECTION 56.—ALONG COLLIERS CREEK AND STATE HIGHWAY 251 ABOUT TWO AND ONE-HALF MILES SOUTHEAST OF COLLIERSTOWN POST OFFICE, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone and shale: strike N. 40° E.; dip 45° SE.	
Collierstown limestone (58 feet)	
15. Limestone, clastic textured; intercalations of irregularly bedded shaly limestones	50
14. Limestone, black-nodular	8
Edinburg formation (745 feet)	
13. Limestone, black, compact; contains buff-weathering shaly partings	25
12. Limestone, black, fine- to medium-grained: contains wavy shaly partings	20
11. Limestone, black, mainly cobbly weathering; shaly partings	135
10. Limestone, black; weathers buff-colored; abundant shaly partings	55
9. Limestone, black, compact; shaly partings	100
8. Limestone, black, compact; contains abundant veins of calcite	23
7. Limestone, black, compact, even-bedded; shaly partings	91
6. Limestone, black, cobbly weathering; shaly partings	31
5. Covered interval	10
4. Limestone, black, compact even-bedded; shaly partings	57
3. Limestone, black, compact, cobbly weathering; 2-inch bed of metabentonite at bottom	12
2. Limestone, black, even-bedded, compact; breaks with conchoidal fracture; abundant shaly partings	178
Analysis of units 2-10, sampled thickness 557 feet: $CaCO_3$, 71.68; $MgCO_3$, 4.20; SiO_2, 20.24; Al_2O_3, 0.48; Fe_2O_3, 1.00; total, 97.60.	
1. Limestone, granular, silty (Botetourt limestone member)	8
Ordovician limestone	

Analysis of two additional hand specimens collected along Colliers Creek are as follows:

1. Shale partings: $CaCO_3$, 57.91; $MgCO_3$, 5.66; SiO_2, 25.27; Al_2O_3, 9.31; Fe_2O_3, 0.79 total, 98.94.
2. Compact limestone: $CaCO_3$, 86.72; $MgCO_3$, 2.93; SiO_2, 10.50; Al_2O_3, 1.80; Fe_2O_3, 0.63; total, 102.58.

It is of interest to note that even though the limestones in the above section contain abundant shaly partings, the content of alumina, as shown by the analyses, is small. Most of the noncarbonate material is silica, probably present as very fine-grained quartz sand.

Another fully exposed section of the Ordovician limestone and shale belt is in the vicinity of Dunkard Church (Pl. 1, loc. 25).

GEOLOGIC SECTION 57.—ABOUT HALF A MILE SOUTH OF DUNKARD CHURCH AND 7 MILES SOUTHWEST OF NATURAL BRIDGE, BOTETOURT COUNTY, VIRGINIA

	Thickness Feet
Collierstown limestone	
Ordovician limestone and shale	
9. Limestone, light-gray, medium- to coarse-grained; thin intercalations of metabentonite	75
Edinburg formation (436 feet)	
8. Limestone, black, slabby to blocky	83
7. Limestone, dark-gray, slabby	21
6. Limestone, buff-gray, cobbly	28
5. Limestone, black, cherty	54
4. Limestone, dark-gray to black, slabby; a few thin shaly partings	83
Analysis of units 4-8, sampled thickness 269 feet: $CaCO_3$, 86.78; $MgCO_3$, 2.23; SiO_2, 8.54; Fe_2O_3, 0.44; Al_2O_3, 1.43; total, 99.42.	
3. Limestone, thin-bedded; shaly partings	107
2. Shale, black	30
1. Limestone, black, slabby	30
Ordovician limestone	

The Barger quarry (Pl. 1, loc. 97) a large producer of crushed stone, is near U. S. Highway 60, in the eastern environs of Lexington. About 150 feet of compact black limestone, typical of certain zones within the belt mapped as Ordovician limestone and shale, is exposed in the quarry. Structurally, this locality is characterized by a small synclinial fold (Pl. 6B), the axis of which trends in a northeasterly direction near the middle of the workings. An analysis of a composite sample of black limestone, veined with white calcite across the quarry shows 82.77 percent calcium carbonate, 6.94 percent magnesium carbonate, and 8.76 percent silica.

An exception to the general impure character of the rocks which comprise the belt of impure limestone and shale was noted at one locality (Pl. 1, loc. 98) near U. S. Highway 11 about 1¾ miles south-

west of the Barger quarry. Here about 60 feet of coarse-grained limestone, apparently of good quality, occur in the upper part of the belt. Similar occurrences of high-calcium limestone have been noted at a few other localities in Shenandoah Valley northeast of the James River district.

The rocks comprising the belt mapped as Ordovician limestone and shale in Warm Springs Valley have been described in a manuscript by Butts as the Lowville limestone. A summary of his description of these rocks is as follows:

> The Lowville is composed almost entirely of limestone in layers of varying, but generally of moderate thickness. Except for the beds of vaughanite, a compact, very fine-grained limestone that breaks with a conchoidal fracture, the freshly broken rock is finely crystalline and bluish-gray. On weathered outcrops the Lowville limestone in mass appearance is dark bluish-gray, which is in evident contrast with the light bluish-gray of the Mosheim, and with the dark to black color of the Lenoir. Another distinctive feature of the Lowville in this region is the occurrence of pinkish or yellowish bands and mottlings which suggest the beginning of the change to the Moccasin facies of the Lowville going southeastward across the strike.

The general character and approximate thickness of the impure limestone, in the vicinity of Healing Springs, modified after Butts, is given in the following section (Pl. 1, loc. 54).

GEOLOGIC SECTION 58.—ALONG A STEEP SLOPE IN THE NORTHWESTERN ENVIRONS OF HEALING SPRINGS VILLAGE, BATH COUNTY, VIRGINIA

	Thickness Feet
Ordovician limestone and shale (530± feet)	
6. Limestone, bluish-gray, nodular, thick-bedded; contains yellow and pink bands and blotches	10
5. Shale and limestone	70
4. Limestone, compact	30
3. Limestone, bluish-gray, finely crystalline; contains shale partings	120
2. Limestone, dove-colored, compact, thick-bedded	80
1. Partly covered; a few exposures of thick-bedded limestone with yellowish bands; may include the Lowville-Lenoir boundary	220±
Limestone	

The rocks immediately overlying the Ordovician limestone and shale in Warm Springs Valley consist of interbedded shale and limestone comprising the lower part of the Martinsburg formation. This horizon is fully displayed in the abandoned roadside quarry (Pl. 1, loc. 99) in the vicinity of Warm Springs. The Martinsburg formation in other parts of the James River district is composed almost entirely of noncarbonate rocks, and is thus mapped with the unit Silurian and Ordovician shale and sandstone.

Upper Silurian and Lower Devonian limestone and sandstone.—The unit mapped (Pl. 1, unit G) as Upper Silurian and Lower Devonian limestone and sandstone includes the Ridgeley sandstone, Keyser limestone, and several members of the Cayuga and Helderberg groups. The upper member of the Cayuga group, Tonoloway limestone, the Keyser limestone, and the Coeymans, New Scotland, and Licking Creek limestones comprising the Helderberg group represent the carbonate formations which were measured and sampled at a few localities in the James River district. Because of local occurrences of high-grade limestone, the rocks comprising this mapped unit are included under the discussion of high-calcium limestone (Geologic Sections 38-49).

Dolomite and Limestone

Rocks, chiefly carbonates, described under this general heading include the following mapped units: Ordovician dolomite and limestone; and, Cambrian dolomite and limestone.

Ordovician dolomite and limestone.—The belt of Ordovician dolomite and limestone (Pl. 1, unit C) includes the Chepultepec limestone at the base with a thickness of from 400 to 600 feet and the overlying Beekmantown formation with an estimated thickness of about 1,500 feet. The Chepultepec formation is predominantly bluish-gray limestone with minor amounts of magnesian limestone and dolomite, whereas the Beekmantown is composed largely of gray, fine- to medium-grained dolomite. Both formations locally contain chert. The composition of the sampled dolomite units generally range from about 35 to 40 percent magnesium carbonate; the limestone units from 85 to 90 percent.

Ordovician dolomite and limestone crop out chiefly in broad areas in the vicinity of Newport, Rockbridge Baths, and Rapps Mill; along the Pulaski-Staunton fault northeast of Lexington, crossing U. S. High-

way 60 between Lexington and Kerrs Creek, and along the trough of the Natural Bridge syncline.

One of the best exposures of the Ordovician dolomite and limestone, although bounded on the northwest side by a fault, is in the vicinity of Steeles Tavern (Pl. 1, loc. 100).

GEOLOGIC SECTION 59.—BEGINNING JUST EAST OF STEELES TAVERN AND EXTENDING NORTHWESTWARD ALONG STATE ROAD 606, AUGUSTA COUNTY, VIRGINIA

	Thickness Feet
Ordovician dolomite and limestone	
Beekmantown formation (1412+ feet)	
53. Limestone and dolomite interbedded; limestone bluish-gray and sparsely cherty; faulted upon Ordovician shale	65+
52. Dolomite, drab-gray, mealy-weathering	3
51. Limestone, magnesian; a few thin dolomite beds	27
50. Dolomite, dark-gray, medium-grained	3
49. Limestone, light- and dark-gray mottled, banded	8
48. Dolomite, dark-gray	2
47. Limestone, banded	7
46. Dolomite, light- to medium-gray, medium-grained	4
45. Limestone, banded; a few thin beds of dolomite	10
44. Dolomite, dark-gray, fine-grained, cherty	13
43. Dolomite, light-gray, fine-grained	5
42. Dolomite, medium-gray, medium-grained	4
41. Dolomite, dark-gray, medium-grained	13
40. Limestone, banded	2
39. Dolomite, medium-gray, fine-grained	5
38. Limestone, slabby	2
37. Dolomite, dark-gray, fine-grained	19
36. Limestone, banded, impure	2
35. Dolomite, medium- to dark-gray, medium-grained	42
34. Dolomite, medium-gray, fine-grained	42
33. Dolomite, medium- to dark-gray, fine-grained, banded	79
32. Limestone, bluish-gray, banded, impure	5
31. Dolomite, dark-gray, fine-grained	18
30. Limestone, bluish-gray	4
29. Dolomite, light- to medium-gray, medium-grained	29
28. Dolomite, medium-gray, medium-grained	98
Analysis of units 28-35, sampled thickness 317 feet: $CaCO_3$, 54.56; $MgCO_3$, 37.50; SiO_2, 7.40; Al_2O_3, 0.52; Fe_2O_3, 0.44; total, 100.42	
27. Chert	2+
26. Dolomite, medium-gray, fine-grained	55
25. Limestone, bluish-gray	5
24. Dolomite, dark-gray	3
23. Limestone, dark bluish-gray, banded	14

22. Dolomite, dark-gray	30
21. Limestone, bluish-gray, banded	4
20. Dolomite, medium-gray, fine-grained	100
19. Limestone, bluish-gray	1
18. Dolomite, dark-gray	6
17. Limestone, bluish-gray	1
16. Dolomite, dark-gray, fine-grained	77
Analysis of units 16-26, sampled thickness 296 feet: $CaCO_3$, 50.94; $MgCO_3$, 36.86; SiO_2, 11.40; Al_2O_3, 0.68; Fe_2O_3, 0.44; total, 100.32.	
15. Limestone, light bluish-gray	6
14. Dolomite, light-gray, fine-grained	70
13. Dolomite, bluish-gray, fine-grained, sparsely cherty	49
12. Dolomite, dark-gray, fine-grained	70
11. Dolomite, light- to medium-gray, medium-grained	94
10. Dolomite, dark-gray, medium-grained; abundant irregular carbonate veins	37
9. Dolomite, medium- to light-gray, fine-grained	94
8. Dolomite, medium-gray, sugary textured	48
7. Dolomite, dark-gray, fine-grained	34
6. Dolomite, brownish-gray	65
5. Dolomite, medium-gray, medium-grained	18
4. Dolomite, dark-gray, fine-grained	18
Analysis of units 4-15, sampled thickness 593 feet: $CaCO_3$, 52.34; $MgCO_3$, 39.32; SiO_2, 7.84; Al_2O_3, 0.28; Fe_2O_3, 0.56; total, 100.34.	
Chepultepec limestone (577 feet)	
3. Limestone, dark bluish-gray, sheared; a few thin wavy siliceous bands	175
2. Mostly covered; a few exposures of sheared bluish-gray limestone	315±
Analysis of units 2 and 3, sampled thickness 490 feet: $CaCO_3$, 88.59; $MgCO_3$, 5.30; SiO_2, 5.36; Al_2O_3, 0.32; Fe_2O_3, 0.12; total, 99.69.	
1. Limestone, dark bluish-gray, straticulate; weathers smoky-gray	87
Cambrian dolomite and limestone	

Another exposure of the Chepultepec showing remarkable similarity in thickness and composition to the preceding section is at locality 101 southeast of Fairfield.

GEOLOGIC SECTION 60.—ALONG STATE ROAD 711 ABOUT 1¼ MILES SOUTHEAST OF FAIRFIELD, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Ordovician dolomite and limestone	
Chepultepec limestone (494 feet)	
3. Limestone, dark bluish-gray, fine-grained	97

2. Dolomite, dark-gray, fine-grained	7
1. Limestone, bluish-gray, fine-grained, sheared	390
Analysis of units 1-3, sampled thickness 494 feet: $CaCO_3$, 87.79; $MgCO_3$, 6.06; SiO_2, 4.80; Al_2O_3, 0.44; Fe_2O_3, 0.20; total, 99.29.	

Cambrian dolomite and limestone

According to Butts (1940, p. 100) the Natural Bridge of Rockbridge County is in the Chepultepec limestone and has an estimated thickness of at least 500 feet. Farther southwest, Ordovician dolomite and limestone is well exposed in a faulted slice along the Pulaski-Staunton fault, extending from the vicinity of Highbridge Church southwestward to a point about one mile southwest of Indian Rock. The thickness and character of the rocks near the southwestern end of this belt (Pl. 1, loc. 102) are given in the following section.

GEOLOGIC SECTION 61.—ALONG STATE ROAD 614 BETWEEN U. S. HIGHWAY 11 AND INDIAN ROCK, BOTETOURT COUNTY, VIRGINIA

	Thickness Feet
Ordovician dolomite and limestone	
Beekmantown formation (lower 484 feet)	
33. Limestone and dolomite; limestone, light-gray, fine-grained; dolomite, pearl-gray	19
32. Dolomite, pearl-gray, brecciated	98
31. Dolomite, cream-colored, brecciated	11
30. Dolomite, medium-gray, medium-grained, sparsely cherty	37
29. Dolomite, medium-gray and cream-colored mottled, medium-grained	28
28. Dolomite, pearl-gray, thick-bedded	25
Analysis of units 28-32, sampled thickness 199 feet: $CaCO_3$, 54.36; $MgCO_3$, 39.40; SiO_2, 5.72; Al_2O_3, 0.16; Fe_2O_3, 0.56; total, 100.20.	
27. Limestone, cherty	4
26. Dolomite, gray, medium-grained	23
25. Dolomite, medium-gray	16
24. Limestone, bluish-gray	5
23. Dolomite, light-gray	7
22. Dolomite, medium-gray, medium-grained	59
21. Dolomite, light- and dark-gray mottled, medium-grained	40
20. Dolomite, light-gray, medium-grained	48
19. Dolomite, light-gray, fine-grained	41
18. Dolomite, light-gray, medium- coarse-grained	23
Analysis of units 18-27, sampled thickness 266 feet: $CaCO_3$, 55.16; $MgCO_3$, 34.83; SiO_2, 9.48; Al_2O_3, 0.25; Fe_2O_3, 0.60; total, 100.31.	

Chepultepec limestone (457 feet)	
17. Largely covered; a few exposures of bluish-gray limestones	53
16. Limestone, bluish-gray	24
15. Limestone and dolomite	25
14. Limestone, bluish-gray, fine-grained	13
13. Dolomite, medium-gray, medium-grained	22
12. Limestone, bluish-gray, very cherty	28
11. Dolomite, bluish-gray, medium-grained	42
10. Dolomite, dark-gray, medium-grained, cherty	34
9. Limestone, dark-bluish-gray, cherty	13
8. Limestone, buff- and bluish-gray mottled; contains diagnostic Chepultepec fossils	106
7. Limestone, bluish-gray, very cherty	6
6. Dolomite, sandy	4
5. Limestone, bluish-gray	8
4. Limestone, bluish-gray	4
3. Limestone and dolomite interbedded	14
2. Dolomite, medium-gray, fine-grained	17
1. Dolomite, medium-gray, very cherty	44
Cambrian dolomite and limestone	

The upper 307 feet of the Ordovician dolomite and limestone belt about 1½ miles northeast of Rocky Point (Pl. 1, loc. 2) contains 53.49 percent calcium carbonate, 35.90 percent magnesium carbonate, and 7.28 percent silica. Sampled dolomite zones of the same unit in the western part of Shenandoah Valley show almost identical chemical composition. For example, the character and chemical composition of the upper part of the Beekmantown southeast of Collierstown (Pl. 1, loc. 103) is given in the following section.

GEOLOGIC SECTION 62.—ALONG COLLIERS CREEK AND STATE HIGHWAY 251 ABOUT TWO MILES SOUTHEAST OF COLLIERSTOWN POST OFFICE, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Ordovician dolomite and limestone	
Beekmantown formation (upper 380 feet)	
23. Limestone, medium-gray, blocky	9
22. Dolomite, medium-gray, medium-grained; 1-foot bed of black chert at base	8
21. Dolomite, medium-gray, medium-grained; contains vugs lined with carbonate minerals	21
20. Chert, black	1
19. Dolomite, dark-gray, medium-grained, cherty	31
18. Dolomite, medium-gray, medium-grained	12
17. Limestone, bluish-gray	3

16. Dolomite, medium-gray; weathers shaly	17
15. Dolomite, medium-gray, sparsely cherty	39
14. Shale, brownish	1
13. Dolomite, medium-gray, medium-grained	16
12. Dolomite, medium-gray, cherty; contains vugs lined with carbonate minerals	8
11. Dolomite with large irregular masses of chert	2
10. Dolomite, light-gray, medium-grained, laminated; a few shaly partings	49
9. Dolomite, light-gray, slightly laminated	20
8. Dolomite, dark-gray, medium coarse-grained	30
Analysis of units 8-23, sampled thickness 262 feet: $CaCO_3$, 53.01; $MgCO_3$, 36.88; SiO_2, 9.52; Al_2O_3, 0.12; Fe_2O_3, 0.60; total, 100.13.	
7. Dolomite, ash-gray; weathers soft and mealy	25
6. Dolomite, light-gray, even-bedded; sparsely cherty near base	39
5. Covered interval	7
4. Dolomite, medium-gray, medium-grained	13
3. Dolomite, medium-gray; contains vugs lined with carbonate minerals; a few thin streaks of shaly and sandy materials	10
2. Dolomite, light-gray, medium-grained	5
1. Dolomite, dark-gray, medium-grained	14
Analysis of units 1-7, sampled thickness 113 feet: $CaCO_3$, 53.60; $MgCO_3$, 38.56; SiO_2, 7.12; Al_2O_3, 0.36; Fe_2O_3, 0.48; total, 100.12.	

An analysis of a sample of the upper 200 feet of the Beekmantown which crops out along Colliers Creek about 700 feet east of the junction of State Highways 251 and 281, shows 51.94 percent calcium carbonate, 34.81 percent magnesium carbonate, and 12.64 percent silica. At this locality chert is prominently displayed in a few beds. Another analysis of a sample of approximately 150 feet of dolomite within the lower part of the Beekmantown southwest of Newport (Pl. 1, loc. 104) shows 52.14 percent calcium carbonate, 40.37 percent magnesium carbonate, and 6.84 percent silica.

One exception to the dominant dolomite content of the upper part of the Beekmantown was noted along U. S. Highway 11 about four miles southwest of Lexington (Pl. 1, loc. 105) where thick limestone zones occur throughout an exposed thickness of about 586 feet. The character of the rocks at this locality is given in the following section.

GEOLOGIC SECTION 63.—ALONG U. S. HIGHWAY 11 EAST OF BUFFALO CREEK AND FOUR MILES SOUTHWEST OF LEXINGTON, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Ordovician dolomite and limestone	
Beekmantown formation (upper 586 feet)	
11. Limestone and dolomite; dolomite, light-gray, limestone, bluish-gray	148
10. Limestone, bluish-gray, slightly brecciated	81
9. Limestone, bluish-gray	4
8. Dolomite, medium-gray	10
7. Dolomite, pearl-gray, fine-grained	45
6. Dolomite, light-gray, brecciated; a thin limestone bed at base	12
5. Limestone, bluish-gray, fine-grained	47
4. Limestone and dolomite, brecciated	48
3. Dolomite, buff-colored, brecciated	36
2. Limestone, light-gray, sandy	67
1. Limestone, thick-bedded, sandy; a few irregular inclusions of dolomite	88

The upper part of the Beekmantown formation which crops out in the middle of Warm Springs Valley from the vicinity of Falling Springs Church northeastward beyond Healing Springs was not studied in detail or sampled during the course of this field investigation. According to Butts, it is predominantly a thick-bedded, finely crystalline, gray dolomite, but with occasional beds of chert, some as much as five feet thick, and also locally, so far as exposed, beds of limestone, twenty to fifty feet thick. Much of the dolomite is very siliceous, the silica, on leaching of the carbonates on weathering, accumulates on the surfaces of the weathered layers as a spongy or cavernous incrustation, a feature which attracts the attention of the observer at once. Another feature worthy of note is the occasional occurrence of oolitic grains, as 1,500 feet east of Tinkertown, where they are abundant in chert.

The best determination or estimate of the thickness of the Beekmantown was made about three-fourths of a mile south of Healing Springs village. Here the width of the Beekmantown outcrop between the anticlinal axis and the top of the formation is 1,000 feet, and the dip, 45° SE., from which the thickness of 700 feet is computed. Adding the thickness from the road down to the ravine, which is 200 feet, the total thickness at this point is 900 feet. Judging from the thickness of the Beekmantown in the vicinity of Staunton, it is probable that at least 600 feet of the formation is below the lowest beds exposed in Warm Springs Valley.

Cambrian dolomite and limestone.—The belt mapped (Pl. 1, unit B) as Cambrian dolomite and limestone includes the Waynesboro (Rome), Elbrook, and Conococheague formations. The Waynesboro formation is extremely heterogeneous, being composed of variable proportions of red and green shale, brown fine-grained sandstone, and impure dolomite and limestone. Except for thin occurrences along major overthrusts in the vicinity of Newport, west of Greenville, and southwest of Buchanan, the Waynesboro is restricted to a broad belt in the eastern part of the James River district, extending southwestward through Vesuvius, Buena Vista, and Buchanan (Pl. 1). Partial exposures of the Waynesboro, although not studied in detail, were observed in the vicinity of Buena Vista, along U. S. Highway 501 between Buena Vista and Glasgow, and at several localities along the Chesapeake and Ohio and the Norfolk and Western railways.

The following section, compiled from a report by Butts (1940, p. 61) shows the general character and thickness of the Waynesboro (Rome) formation east of Buchanan (Pl. 1, loc. 106).

GEOLOGIC SECTION 64.—ALONG THE CHESAPEAKE AND OHIO RAILWAY ABOUT HALF A MILE NORTHEAST OF BUCHANAN, BOTETOURT COUNTY, VIRGINIA

	Thickness Feet
Cambrian dolomite and limestone	
Waynesboro formation (1886+ feet)	
18. Shale; partly exposed; probably extends nearly to the top of the Waynesboro	300
17. Limestone, drab-colored; weathers white; partly exposed	180
16. Shale	500
15. Shale with a few layers of limestone and dolomite	230
14. Limestone, thick-bedded; weathers white; a layer of pearl-gray compact limestone at top	20
13. Limestone, blue, ribbony	165
12. Largely covered; a few beds of limestone exposed	100
11. Limestone	100
10. Dolomite, mottled	30
9. Shale; red streaks and thin layers of limestone and dolomite	100
8. Limestone or dolomite, compact	5
7. Limestone and dolomite; weathers yellow; partly thin bedded and ribbony	100
6. Shale, red	2
5. Shale, green	10
4. Shale, red	2
3. Shale, green	15
2. Shale, red	2
1. Dolomite, gray, shaly	25
Cambrian dolomite	

The upper part, approximately half of the Waynesboro formation, is fully exposed along the Chesapeake and Ohio Railway beginning about one-fourth of a mile east of Indian Rock (Pl. 1, loc. 107). A detailed description of the rocks comprising this interval is given in the following section.

GEOLOGIC SECTION 65.—ALONG THE CHESAPEAKE AND OHIO RAILWAY ABOUT ONE-FOURTH OF A MILE EAST OF INDIAN ROCK, BOTETOURT COUNTY, VIRGINIA

	Thickness *Feet*
Cambrian dolomite and limestone	
Waynesboro formation (upper 957 feet)	
30. Shale, buff-gray; a few thin beds of dolomite	14
29. Dolomite, gray, fine-grained	21
28. Dolomite, shaly weathering	9
27. Dolomite, gray, medium-grained	59
26. Shale, red and green	41
25. Dolomite, light-gray to brownish-gray, laminated	17
24. Shale, red	13
23. Dolomite, light-gray, fine-grained	7
22. Shale, red; weathers to shoepeg fragments	14
21. Dolomite and shale	11
20. Shale, red	12
19. Shale, red and green	59
18. Dolomite and shale	4
17. Shale, red	15
16. Dolomite and shale	18
15. Shale, red	2
14. Dolomite, light-gray, fine-grained	15
13. Dolomite and limestone; limestone weathers irregularly; few layers have blotched surfaces	156
12. Dolomite, light-gray; weathers brown	25
11. Dolomite and shale	53
10. Covered interval	162
9. Limestone and dolomite; a part of the limestone weathers to a spongy looking rock resembling clinkers	90
8. Dolomite with shale partings	27
7. Limestone, bluish-gray, fine-grained	4
6. Shale, red and brown	53
5. Dolomite, light-gray	1
4. Shale, red	8
3. Dolomite, light-gray, sandy	33
2. Limestone, bluish-gray	9
1. Sandstone and shale, drab colored; covered at base	5

The Lone Jack Limestone Company quarries are located along the Norfolk and Western Railway and North River about 1½ miles

northeast of Glasgow. When visited in 1956, crushed stone was being produced from Cambrian quartzite (Pl. 1, loc. 108), near the northeastern end of Sallings Mountain and from dolomite in a newly developed quarry about half a mile northwest of the original workings (Pl. 1, loc. 109). This dolomite is tentatively identified as a part of the Waynesboro formation, since it is closely overlain to the northwest by typical red shale. The rocks were not sampled in the quarry, but about 150 feet of light to dark bluish-gray dolomite, perhaps in the lower part of the Waynesboro formation, which crops out along the Norfolk and Western Railway 500 yards southeast of locality 108 contains 51.34 percent calcium carbonate, 39.76 percent magnesium carbonate, and 7.64 percent silica (Table 7). Other similar appearing dolomite units occurring near the base of the Waynesboro formation are included in a few of the sections describing the high-magnesium dolomite.

The Elbrook formation, overlying the Waynesboro, is composed largely of about 2,000 feet of dolomite with minor amounts of limestone. Many of the dolomite layers are impure, commonly weathering to shaly plates. The sampled zones of the more massively bedded dolomites generally contain from about 37 to 40 percent magnesium carbonate and from 7 to 9 percent silica. The overlying Conococheague formation, also about 2,000 feet thick, is composed largely of impure limestone, but with minor amounts of dolomite, in the belts east of the Pulaski fault. Interbedded dolomite comprises approximately half of the total thickness in the western belts. Sampled units of limestone contain from 71 to 89 percent calcium carbonate; those of dolomite from 33 to 38 percent magnesium carbonate. Silica varies from about 7 to 17 percent.

One of the best exposures of the Conococheague and the upper three-fourths of the Elbrook is along State Highway 56, southeast of Steeles Tavern (Pl. 1, loc. 110).

GEOLOGIC SECTION 66.—ALONG STATE HIGHWAY 56 EXTENDING SOUTHEAST OF STEELES TAVERN, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Cambrian dolomite and limestone	
Conococheague limestone (1898 feet)	
86. Limestone, straticulate, very cherty; a few thin beds of dolomite	12
85. Limestone, dark bluish-gray, sparsely cherty; a few thin beds of dolomite	180

84. Limestone, dark-gray; contains prominent crinkly siliceous bands	80
83. Limestone, dark bluish-gray; a few lenses of black chert; $CaCO_3$, 88.79; $MgCO_3$, 3.73; SiO_2, 6.80; Al_2O_3, 0.40; Fe_2O_3, 0.28; total, 100.00	125
82. Limestone, dark-gray, banded, siliceous	186
81. Covered interval; limestone float	60
80. Dolomite, dark bluish-gray	10
79. Limestone, dark bluish-gray, banded, siliceous	78
78. Sandstone, and sandy dolomite	6
77. Dolomite, bluish-gray, sandy	9
76. Dolomite, bluish-gray	19
75. Dolomite, sandy	7
74. Limestone, light-gray	2
73. Sandstone	2
72. Limestone, dark-gray, banded	12
71. Dolomite, banded	3
70. Limestone, dark-gray, banded, siliceous	19
69. Sandstone	4
68. Covered interval; abundant sandstone float	5
67. Limestone, banded, siliceous; contains disseminated quartz grains	30
66. Sandstone and sandy dolomite	3
65. Shale, buff, limy	2
64. Dolomite, dark-gray, medium-grained	8
63. Limestone, banded, siliceous	18
62. Limestone, dark-gray, banded; contains disseminated quartz grains	20
61. Dolomite, dark bluish-gray, fine-grained	22
60. Covered interval	11
59. Limestone, banded, siliceous	5
58. Dolomite within thin sandstone layers	5
57. Limestone, banded, siliceous, weathers to drab-colored shale	7
56. Sandstone	3
55. Limestone, bluish-gray, banded; a few thin bands of dolomite	6
54. Dolomite	2
53. Dolomite, dark bluish-gray	10
52. Limestone, dark-gray, banded, siliceous	259
51. Dolomite, dark-gray, shaly	14
50. Limestone, dark-gray, banded, siliceous	40
49. Dolomite with thin limestone partings	8
48. Limestone, dark-gray, banded, siliceous	19
47. Covered interval	92
46. Dolomite, medium-gray, brecciated	82
45. Dolomite, dark- to medium-gray	94
44. Dolomite and sandstone	6
43. Dolomite, sandy, coarse-grained	11
42. Dolomite, dark-gray, banded, medium-grained	13

41. Dolomite, dark-gray, banded; a few thin beds of banded limestone 76
Analysis of units 41-46, sampled thickness 282 feet: $CaCO_3$, 52.14; $MgCO_3$, 32.38; SiO_2, 14.12; Al_2O_3, 0.56; Fe_2O_3, 0.96; total, 100.16.
40. Limestone, banded, siliceous; a few thin beds of dolomite.. 83
39. Sandstone, light buff-gray..... 4
38. Limestone, banded, siliceous..... 48
37. Limestone, banded, siliceous, sparsely cherty..... 16
36. Dolomite, sandy 1
35. Limestone, bluish-gray, banded, siliceous..... 41
34. Dolomite, medium dark-gray..... 16
33. Limestone, bluish-gray, banded, siliceous..... 4

Elbrook dolomite (upper 1505 feet)

32. Dolomite, medium-gray 133
31. Limestone and dolomite interbedded..... 7
30. Mostly covered; a few exposures of dark-gray, medium-grained dolomite 17
29. Dolomite, dark-gray, medium-grained, sparsely cherty..... 61
28. Dolomite, dark-gray, fine-grained..... 28
27. Dolomite, dark-gray, medium-grained, thick-bedded..... 180
Analysis of units 27-32, sampled thickness 426 feet: $CaCO_3$, 52.96; $MgCO_3$, 37.22; SiO_2, 9.00; Al_2O_3, 0.52; Fe_2O_3, 0.88; total, 100.58.
26. Dolomite, medium-gray, medium-grained, sparsely cherty.. 38
25. Dolomite, platy 58
24. Sandstone, deeply weathered..... 3
23. Shale, dark-gray, calcareous..... 16
22. Dolomite; weathers shaly..... 42
21. Dolomite, brecciated 31
20. Sandstone, and shale..... 18
19. Dolomite, dark-gray; thick-bedded; a few interbedded platy layers 8
18. Mostly covered; a few exposures of platy dolomite..... 420±
17. Dolomite, dark-gray, sugary textured; a few layers of drab-gray, platy dolomite..... 93
16. Dolomite, dark-gray, banded..... 5
15. Dolomite, dark-gray, fine-grained, impure..... 42
14. Dolomite, medium-gray, sandy..... 1
13. Dolomite, medium-gray, fine-grained..... 2
12. Dolomite, dark- and drab-gray mottled, brecciated..... 10
11. Dolomite, light-gray, thick-bedded..... 13
10. Limestone, dark-gray, banded..... 3
9. Dolomite, drab-gray, brecciated..... 29
8. Dolomite, light-gray, thick-bedded; disseminated quartz sand 8
7. Dolomite, drab-gray, fine-grained, platy..... 10
6. Dolomite, medium- to dark-gray; a few beds weather shaly 92
5. Limestone, dark-gray, banded..... 6
4. Limestone, sandy 1

3. Limestone, clayey; weathers to soft shale	22
2. Dolomite, dark-gray, impure	13
1. Dolomite, clayey, banded; weathers to soft shale; covered at the base	95

There are no distinct differences in rock character in the above section which could be used in locating a precise boundary between the Elbrook and Conococheague formations. It is probable that units 33 to 86, with an aggregate thickness of 1,899 feet, comprise most of the Conococheague formation. Certainly at no great distance lower in section the rocks are chiefly dolomite, some of which weathers to shaly platy fragments characteristic of the Elbrook.

Another excellent exposure of the rocks comprising the belt of Cambrian dolomite and limestone is in the broad area northwest of Buena Vista. The character and thickness of the rocks which crop out in the eastern part of this area near Buena Vista (Pl. 1, loc. 111) are given in the following section.

GEOLOGIC SECTION 67.—ALONG THE CHESAPEAKE AND OHIO RAILWAY AND THE NORFOLK AND WESTERN RAILWAY EXTENDING NORTHWEST OF BUENA VISTA, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Cambrian dolomite and limestone	
Conococheague limestone (lower 1532 feet)	
58. Limestone, bluish-gray, fine-grained; crinkly siliceous partings	85
57. Dolomite, yellowish-brown, mealy-weathering	5
56. Limestone, dark-gray, fine-grained, banded; veins of calcite and quartz	50
55. Limestone, dark-gray, thinly-banded	71
Analysis of units 55-58, sampled thickness 211 feet: $CaCO_3$, 76.92; $MgCO_3$, 6.57; SiO_2, 15.08; Al_2O_3, 0.92; Fe_2O_3, 0.72; total, 100.21.	
54. Limestone, light-gray to cream-colored, medium-grained	83
53. Limestone and dolomite, light-gray	72
52. Sandstone	2
51. Limestone, light-gray to cream-colored, medium-grained; a few impure greenish streaks	115
Analysis of units 51 and 53, sampled thickness 187 feet: $CaCO_3$, 72.30; $MgCO_3$, 9.42; SiO_2, 17.16; Al_2O_3, 0.72; Fe_2O_3, 0.60; total, 100.20.	
50. Largely covered; a few exposures of bluish-gray, banded limestone	117
49. Limestone, dark-gray, banded	67
48. Limestone, light-bluish-gray to cream-colored, medium-grained; cherty near base	120

47. Limestone, dark-gray, fine- to medium-grained, banded.... 371
46. Limestone, light-gray to cream-colored, medium-grained... 25
Analysis of units 46-50, sampled thickness 700 feet: $CaCO_3$, 80.34; $MgCO_3$, 6.33; SiO_2, 12.40; Al_2O_3, 0.40; Fe_2O_3, 0.64; total, 100.11.
45. Covered interval 142
44. Limestone, bluish-gray, banded..... 134
43. Limestone, light- and dark-gray, mottled..... 2
42. Dolomite, light-gray, fine-grained, platy..... 18
41. Limestone, dark-gray, banded..... 10
40. Dolomite, light-gray, platy..... 10
39. Limestone, dark-gray, banded..... 9
38. Dolomite, light-gray, fine-grained..... 6
37. Limestone, banded, cherty; tentatively assigned as base of Conococheague formation 18

Elbrook dolomite (2271 feet)

36. Covered interval 56
35. Dolomite, light-gray, fine-grained..... 21
34. Dolomite, fine-grained, brecciated..... 7
33. Dolomite, light-gray 5
32. Dolomite, bluish-gray, fine-grained..... 22
31. Dolomite, shaly 3
30. Dolomite, dark-gray, fine-grained; black chert nodules near middle 33
29. Dolomite, dark bluish-gray; thin bedded..... 48
28. Dolomite, dark bluish-gray; weathers shaly..... 125
27. Dolomite, sandy 1
26. Dolomite, light-gray; contains thin partings of sandy dolomite 19
25. Dolomite, bluish-gray, laminated; weathers cream-colored.. 35
Analysis of units 25-34, sampled thickness 298 feet: $CaCO_3$, 51.66; $MgCO_3$, 38.37; SiO_2, 9.12; Al_2O_3, 0.08; Fe_2O_3, 1.04; total, 100.27.
24. Dolomite, mainly dark- to medium-gray, fine-grained; thin bed of edgewise conglomerate at base..... 364
23. Dolomite, bluish-gray, fine-grained..... 40
Analysis of units 23 and 24, sampled thickness 404 feet: $CaCO_3$, 50.54; $MgCO_3$, 39.05; SiO_2, 9.44; Al_2O_3, 0.52; Fe_2O_3, 0.68; total, 100.23.
22. Limestone, dark-gray 3
21. Dolomite, dark-gray, fine-grained, shaly weathering..... 107
20. Dolomite, light-gray, thick-bedded..... 11
19. Dolomite, light-gray, shaly weathering..... 31
18. Dolomite, drab-gray, shaly weathering..... 14
17. Largely covered; a few exposures of shale..... 130
16. Dolomite, light-gray 7
15. Dolomite, bluish-gray 10
14. Covered interval 150

13. Partly covered; a few exposures of an ocherous weathering limestone and shale	235
12. Dolomite, buff-gray	38
11. Dolomite with greenish-gray shale partings	22
10. Limestone, banded, impure	5
9. Dolomite, drab-gray, shaly; weathers mealy	18
8. Limestone, dark-gray, banded	10
7. Dolomite, light-tan, banded	35
6. Dolomite and limestone, laminated	18
5. Limestone, bluish-gray, banded	11
4. Dolomite, dark-gray, shaly	50
3. Covered interval	106
2. Partly covered; a few exposures of banded limestone and blocky dark-gray dolomite	285
1. Dolomite, platy, impure; lower boundary uncertain	196

Waynesboro formation

A total thickness of 2,271 feet of rocks, largely impure dolomite, is assigned to the Elbrook formation (units 1-36) in the above section. Southwestward along the strike of this belt at Buffalo Forge (Pl. 1, loc. 112) the upper part of the Elbrook is composed of dark-bluish-gray, fine- to medium-grained dolomite. A composite sample of the upper 200 feet of dolomite which crops out east and west of State Road 608 at this locality contains 53.56 percent calcium carbonate, 42.53 percent magnesium carbonate, and only 3.56 percent silica, (Table 7). This analysis represents the highest-grade dolomite sampled from the belt of Cambrian dolomite and limestone in the eastern part of the James River district.

The character and thickness of the Conococheague southeast of Natural Bridge (Pl. 1, loc. 113) are given in the following section.

GEOLOGIC SECTION 68.—ALONG STATE ROAD 608 AND STATE HIGHWAY 249 SOUTHEAST OF NATURAL BRIDGE, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Cambrian dolomite and limestone	
Conococheague limestone (2129 feet)	
29. Limestone dark bluish-gray; contains crinkly siliceous laminae and a few thin dolomite beds	35
28. Limestone and dolomite, dark-gray	175
27. Limestone, dark bluish-gray, cherty; two thin sandstone beds near top	68
26. Covered interval	95
25. Limestone and dolomite, dark bluish-gray; partly covered	193
24. Dolomite, shaly; a few rusty-weathering sandstone beds	49

23. Dolomite, cream colored, finely laminated	8
22. Limestone and dolomite, dark bluish-gray	4
21. Dolomite, light-gray; laminated; a few sandy layers near top	2
20. Limestone and dolomite, dark bluish-gray	16
19. Sandstone float	16
18. Limestone, dark-gray, fine-grained, shaly weathering	65
17. Limestone and dolomite, dark bluish gray, a few beds weather to buff-colored gritty shale	22
16. Sandstone and buff-colored shale	8
15. Limestone and dolomite, dark bluish-gray	29
14. Sandstone float	29
13. Limestone, dark bluish-gray, laminated; a few reddish streaks and occasional thin layers of dolomite	36
12. Covered interval	54
11. Limestone and dolomite; contains crinkly siliceous laminae	53
10. Dolomite, light-gray; a part weathers shaly	44
9. Limestone, bluish-gray, laminated; a few buff-colored dolomite beds	39
8. Limestone and dolomite, gray, fine-grained; partly covered	524
7. Covered interval	193
6. Dolomite, bluish-gray, fine-grained; partly covered	117
5. Covered interval	90
4. Dolomite, bluish-gray, medium-grained; partly covered	108
3. Dolomite, gray, cherty	19
2. Covered interval; abundant sandstone float	31
1. Shale, buff-colored; a few sandstone streaks	7

Elbrook dolomite

Southwest of Rockbridge-Botetourt County line the exposed part of the belt of Cambrian dolomite and limestone east of the Pulaski-Staunton fault, includes about the lower three-fourths of the Elbrook formation. The character and thickness of these rocks which are fully exposed in the vicinity of Indian Rock (Pl. 1, loc. 114) are as follows:

GEOLOGIC SECTION 69.—ALONG CHESAPEAKE AND OHIO RAILWAY AND STATE ROAD 614 IN THE VICINITY OF INDIAN ROCK, BOTETOURT COUNTY, VIRGINIA

	Thickness Feet
Cambrian dolomite and limestone	
Elbrook dolomite (lower 1347 feet)	
27. Dolomite with shaly partings	215
26. Dolomite, buff-colored, platy; a few thin shaly beds	146
25. Dolomite, dark bluish-gray	11
24. Dolomite, buff-colored; shaly weathering	7
23. Dolomite, dark bluish-gray, medium-bedded	9
22. Dolomite, platy	33
21. Dolomite, dark bluish-gray, medium-grained; abundant carbonate veins	56

20. Dolomite, buff-colored; shaly weathering	32
19. Dolomite, dark bluish-gray, medium-bedded	11
18. Dolomite, buff-colored, platy	138
17. Dolomite, dark bluish-gray, fine-grained, thick-bedded	13
16. Dolomite, dark-gray to buff-colored, fine-grained, slabby weathering	31
15. Dolomite, medium-gray, fine-grained	20
14. Dolomite, light-gray, shaly weathering	117
13. Dolomite, light-gray, thick-bedded; weathers buff-colored	19
12. Dolomite, light-gray, medium thick-bedded	80
11. Dolomite, light-gray, shaly weathering	184
10. Limestone, light-gray, to pinkish-gray	10
9. Dolomite, dark-gray	21
8. Limestone, light-gray to salmon-colored, fine-grained	6
7. Dolomite, light-gray	7
6. Limestone, bluish-gray	4
5. Dolomite, light-gray	60
4. Dolomite, light-gray, shaly weathering	29
3. Shale and interbedded dolomite	61
2. Dolomite, light-gray, shaly weathering	16
1. Dolomite, gray, thick-bedded	11

Another excellent exposure of about 1,300 feet of impure dolomite and limestone comprising the middle part of the Elbrook formation was observed along U. S. Highway 11, just south of Buffalo Creek (Pl. 1, loc. 115). Although the Elbrook is characterized by abundant impure beds which weather to thin shaly plates, a considerable portion of the formation is composed of massively bedded dense dolomite, which is used locally for crushed stone. One of these thick zones of dolomite described in the following section is exposed in a quarry formerly operated by the State Department of Highways about five miles northeast of Lexington (Pl. 1, loc. 116).

GEOLOGIC SECTION 70.—INACTIVE QUARRY ALONG U. S. HIGHWAY 11 ABOUT FIVE MILES NORTHEAST OF LEXINGTON, ROCKBRIDGE COUNTY, VIRGINIA

	Thickness Feet
Cambrian dolomite and limestone	
Elbrook dolomite (near middle, 180 feet)	
4. Dolomite, light-gray, fine-grained; weathers ash-gray	17
3. Limestone, bluish-gray, banded	4
2. Dolomite, bluish-gray, medium-grained; weathers ash-gray	17
1. Dolomite, dark bluish-gray, medium- to fine-grained	142
Analysis of units 1-4, sampled thickness, 180 feet: $CaCO_3$, 56.56; $MgCO_3$, 33.56; SiO_2, 9.36; Al_2O_3, 0.40; Fe_2O_3, 0.60; total 100.48.	

The Department of Highways is producing stone for highway construction from a similar zone of Elbrook dolomite in the Greenville quarry (Pl. 1, loc. 116a), which is located about two miles northwest of Greenville, Augusta County, Virginia.

A part of the belt of Cambrian dolomite and limestone crops out at several localities east and west of Pulaski-Staunton fault, but no continuously exposed sections of the full thickness of these rocks were observed. The character and thickness of the Conococheague and about the upper half of the Elbrook east of Newport (Pl. 1, loc. 117) are given in the following section.

GEOLOGIC SECTION 71.—ALONG STATE ROAD 675 AND ABOUT 2½ MILES EAST OF NEWPORT, AUGUSTA COUNTY, VIRGINIA

	Thickness Feet
Cambrian dolomite and limestone	
Conococheague limestone (lower 1456 feet)	
105. Dolomite, medium- to light-gray, medium grained	100
104. Limestone and dolomite	30
103. Dolomite, medium-gray, fine-grained	5
102. Partly covered; a few beds of sandstone and sandy dolomite	47
101. Dolomite, medium-gray, fine-grained; weathers brownish-gray; a few beds of sandy dolomite	23
100. Limestone, bluish-gray, medium-grained, oolitic	19
99. Dolomite, dark-gray, thin bedded, banded	18
98. Covered interval; abundant sandstone float	16
97. Limestone and dolomite; limestone contains crinkly siliceous laminae	34
96. Dolomite, medium-gray, streaked with thin crinkly buff-colored partings and thin sandstone bed at base	15
95. Limestone, bluish-gray, banded, siliceous	7
94. Dolomite, light-gray; weathers light-brown	11
93. Limestone, conglomeratic, sandy	3
92. Limestone, dark bluish-gray, conglomeratic, oolitic	15
91. Dolomite, light-gray and pink mottled	8
90. Partly covered; a few exposures of gnarly weathering dolomite and abundant sandstone float	43
89. Limestone, bluish-gray, banded, siliceous	15
88. Limestone, bluish-gray, oolitic	40
87. Sandstone and sandy dolomite	8
86. Dolomite, greenish-gray, impure	5
85. Limestone, bluish-gray; contains crinkly siliceous laminae	5
84. Limestone and dolomite; limestone contains crinkly siliceous laminae	14
83. Dolomite, dark-gray, laminated	3
82. Sandstone	5
81. Dolomite, dark-gray, fine-grained; a few layers of banded siliceous limestone and edgewise conglomerate	38

80. Limestone, conglomeratic, oolitic..... 14
79. Limestone, dark bluish-gray, banded, siliceous..... 8
78. Limestone, bluish-gray; a few beds of dolomite..... 35
77. Dolomite, medium-gray, fine-grained..... 10
76. Dolomite and edgewise conglomerate..... 20
75. Limestone, bluish-gray, banded, siliceous..... 58
74. Dolomite, dark-gray 7
73. Limestone, conglomeratic, oolitic..... 10
72. Dolomite, dark-gray, straticulate..... 11
71. Limestone, conglomeratic, oolitic..... 6
70. Dolomite, dark bluish-gray, fine-grained, straticulate..... 12
69. Dolomite, medium- to light-gray, fine-grained; contains layers of oolitic limestone..... 16
68. Limestone, bluish-gray; contains crinkly siliceous laminae.. 55
67. Dolomite, dark-gray, fine-grained..... 8
66. Limestone, oolitic; a few beds of edgewise conglomerate... 42
65. Limestone, bluish-gray; contains crinkly siliceous laminae.. 56
64. Dolomite, dark-gray, fine-grained..... 40
63. Dolomite, dark-gray, fine-grained, shaly weathering..... 24
62. Dolomite, dark-gray, medium-grained, fractured..... 132
61. Dolomite, dark-gray, medium- to fine-grained..... 77
60. Dolomite, medium- to dark bluish-gray, medium-grained.... 35
59. Dolomite, medium-gray, medium-grained, cherty..... 57
58. Dolomite, dark-gray, medium- to fine-grained..... 20
57. Dolomite, dark-gray, medium- to fine-grained..... 13
Analysis of units 57-64, sampled thickness, 398 feet: $CaCO_3$, 51.34; $MgCO_3$, 38.02; SiO_2, 9.68; Al_2O_3, 0.52; Fe_2O_3, 0.64; total, 100.20.
56. Dolomite, dark-gray, fine-grained, laminated..... 9
55. Largely covered; a few exposures of medium-gray dolomite 13
54. Sandstone and sandy dolomite..... 5
53. Dolomite, medium-gray, medium-grained..... 8
52. Sandstone and sandy dolomite..... 6
51. Dolomite, medium- to dark-gray, medium-grained; contains thin sandstones and sandy shales..... 47
50. Dolomite, dark-gray, fine-grained, fractured; a few shaly beds 53
49. Partly covered; many sandstone beds..... 22

Elbrook dolomite (upper 1310 feet)

48. Dolomite, medium-gray, medium-grained; a few intercalations of impure dolomite which weathers to shale..... 63
47. Dolomite, light- to dark-gray..... 85
46. Dolomite, dark-gray 77
45. Largely covered; a few exposures of dark-gray dolomite.... 35
44. Dolomite, light- to dark-gray, medium-grained..... 75
43. Dolomite, light- to dark-gray..... 52
42. Dolomite, medium-gray, medium-grained; a few beds of shaly dolomite 97
41. Dolomite, light-gray, fine-grained..... 30

40. Limestone, bluish-gray	3
39. Dolomite, light-gray to cream-colored, fine-grained	37
38. Dolomite, medium light-gray to tan-colored mottled	40
37. Covered interval	12
36. Dolomite, medium-gray, fine-grained; a few pinkish-colored beds	38
Analysis of units 36-47, sampled thickness 581 feet: $CaCO_3$, 52.04; $MgCO_3$, 38.37; SiO_2, 9.40; Al_2O_3, 0.08; Fe_2O_3, 0.56; total, 100.45.	
35. Dolomite, dark-gray, fine-grained	49
34. Limestone, bluish-gray, medium-grained	5
33. Dolomite, dark-gray, fine-grained	13
32. Dolomite, light-gray, fine-grained	14
31. Limestone, bluish-gray, irregularly banded	4
30. Dolomite, dark-gray, fine-grained	21
29. Dolomite, medium- to light-gray, fine-grained	14
28. Limestone, bluish-gray, banded crumbly	3
27. Dolomite, dark-gray, fine-grained	68
26. Limestone, bluish-gray	8
25. Covered interval	60
24. Dolomite, light-gray, fine-grained	15
23. Limestone, bluish-gray	3
22. Dolomite, medium-gray, sandy	5
21. Limestone, bluish-gray, oolitic	3
20. Dolomite, medium-gray, fine-grained	42
19. Limestone, bluish-gray, fine-grained	4
18. Dolomite, dark-gray to cream-colored, fine-grained	40
17. Dolomite, dark-gray, fine-grained; weathers shaly	38
16. Dolomite, medium- to dark-gray; weathers buff-colored	17
15. Dolomite, dark-gray, brecciated	6
14. Dolomite, dark-gray; weathers buff-colored	46
13. Dolomite, dark-gray, fine-grained	10
12. Limestone, bluish-gray, banded; a few thin beds of bluish-gray dolomite	8
11. Dolomite, dark-gray, fine-grained; weathers shaly	9
10. Limestone, bluish-gray, banded, oolitic; a few shaly partings	10
9. Dolomite, dark-gray, fine-grained	15
8. Limestone, bluish-gray, banded	6
7. Dolomite, dark-gray, fine-grained, platy	13
6. Limestone, bluish-gray, banded	16
5. Dolomite, light-gray, brecciated	45
4. Limestone, bluish-gray, oolitic	10
3. Limestone, bluish-gray, banded	3
2. Limestone, bluish-gray	13
1. Limestone, bluish-gray, banded; weathers shaly	30

The boundary between the Conococheague and Elbrook in the area east of Newport is not evident, since the Conococheague in the

western belts contains abundant dolomite similar to that which occurs in a part of the underlying Elbrook. Correlation based on the distinctive sandstones in the Conococheague would place the boundary at least as low as unit 49 in Geologic Section 7. Sampled units of dolomite from both the Conococheague and Elbrook formations show almost identical chemical composition, containing about 52 percent calcium carbonate, 38 percent magnesium carbonate, and 9 percent silica. The lower 75 feet of the Elbrook, consisting of impure limestone closely underlain by red shaly mudrock, along State Highway 251, about 1½ miles northeast of Newport (Pl. 1, loc. 118) contains 83.17 percent calcium carbonate, 6.36 percent magnesium carbonate, and 9.16 percent silica (Table 7).

The broad belt of carbonate rocks, chiefly dolomite, mapped (Pl. 1) as Cambrian dolomite and limestone in Fincastle Valley, includes the Elbrook and Conococheague formations. These formations, due to repetition by folding, are exposed at many places along the steep slopes adjacent to James River between Buchanan and Eagle Rock. One representative exposure at a locality about 2½ miles southeast of Eagle Rock (Pl. 1, loc. 119) is described in the following section.

GEOLOGIC SECTION 72.—ALONG CHESAPEAKE AND OHIO RAILWAY AND JAMES RIVER ABOUT ONE HALF MILE WEST OF STATE ROAD 688 AND 2½ MILES SOUTHEAST OF EAGLE ROCK, BOTETOURT COUNTY, VIRGINIA

	Thickness Feet
Cambrian dolomite and limestone	
Elbrook dolomite (middle 1257 feet)	
8. Limestone, banded	3
7. Dolomite, gray, fine-grained	302
6. Dolomite, dark-gray, fine- to medium-grained	201
5. Dolomite, gray, fine- to medium-grained; a few brownish streaks	120
Analysis of units 5-8, sampled thickness 626 feet: $CaCO_3$, 54.56; $MgCO_3$, 38.62; SiO_2, 3.85; Al_2O_3, 2.35; Fe_2O_3, 0.88; total, 100.26.	
4. Dolomite, medium-gray	235
3. Dolomite, gray; a few thin sandy streaks	123
2. Dolomite, dark- to medium-gray; a few thin sandy streaks	106
1. Dolomite, light- to medium-gray	167
Analysis of units 1-4, sampled thickness 631 feet: $CaCO_3$, 54.16; $MgCO_3$, 40.65; SiO_2, 3.62; Al_2O_3, 0.81; Fe_2O_3, 1.14; total, 100.38.	

The above section underlies a thin zone of shaly dolomite which appears to be repeated in a tightly compressed anticlinal fold. Dolomite cropping out along the Chesapeake and Ohio Railway east of this structure is thought to represent units 1 to 4 in Geologic Section 72. A composite sample of approximately 700 feet of dolomite at this locality contains 49.42 percent calcium carbonate, 40.03 percent magnesium carbonate, and 7.06 percent silica. A detailed analysis of this thick unit of dolomite is given in Table 7. Another excellent exposure of the upper part of the Elbrook formation is along State Highway 43, about 2½ miles northeast of Springwood. Here much of the dolomite is sheared and brecciated as a result of its proximity to the Pulaski-Staunton fault (Pl. 1, loc. 120).

GEOLOGIC SECTION 73.—ALONG STATE HIGHWAY 43 ABOUT 2½ MILES NORTHEAST OF SPRINGWOOD AND 5 MILES SOUTHEAST OF EAGLE ROCK, BOTETOURT COUNTY, VIRGINIA

	Thickness Feet
Cambrian dolomite and limestone	
Elbrook dolomite (middle 445 feet)	
11. Dolomite, dark bluish-gray, dense; abundant white carbonate veins	30
10. Conglomerate, shaly, crushed	14
9. Dolomite, dark bluish-gray, shaly, thin-bedded	19
8. Shale, bluish-gray, limy, jointed	29
7. Dolomite, light-gray, medium-grained	8
6. Dolomite, dark bluish-gray, fine-grained; abundant carbonate veins	33
5. Dolomite, dark bluish-gray, shaly, platy	21
4. Dolomite, bluish-gray, crushed	42
3. Limestone, dark bluish-gray, fine-grained, magnesian; abundant carbonate veins	52
2. Dolomite, dark bluish-gray, platy	41
1. Dolomite, dark bluish-gray, crushed	156

The results of field studies and chemical analyses indicate that the unit mapped (Pl. 1) as Cambrian dolomite and limestone in the James River district does not contain quarriable thicknesses of either high-calcium limestone or high-magnesium dolomite.

Crushed and Broken Stone

Stone used as an aggregate in highway construction is dependent primarily upon certain physical properties. These tests include Specific Gravity, Absorption, and the Los Angeles Abrasion Loss. The

abrasion loss is a comparative quality of the aggregate based upon a blend of toughness and resistance to abrasion. The Virginia Department of Highways uses three gradings and designates the quality as A, B, and C. The requirement for Grade "A" stone is a loss not exceeding 35 percent.

In Table 8, the writer is indebted to the Division of Tests, Virginia Department of Highways, for all of the data. The samples of limestone and dolomite were collected by the writer, while employed by the Virginia Geological Survey, and submitted to the late Mr. Shreve Clark, Testing Engineer, for testing. The reader is referred to reports prepared by W. T. Parrott, Geologist, Virginia Department of Highways, for additional tests of the physical properties of rocks in active quarries and potential quarry sites within the James River district.

TABLES AND PLATES

TABLE 7.—CHEMICAL COMPOSITION OF CARBONATE ROCKS IN THE JAMES RIVER DISTRICT WEST OF THE BLUE RIDGE, VIRGINIA

(Froehling & Robertson, Inc., and John H. Yoe,[1] Analysts)

Map No. Pl. 1	Geologic Section			$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	Total	Locality
	No.	Units Sampled	Thickness Feet							
2	2	7	144	97.75	1.00	0.33	0.36	0.44	99.88	Along State Road 610 and Roaring Run about 1½ miles northeast of Rocky Point.
		3–4	92	96.71	1.33	0.74	0.31	0.50	99.59	
		1	307	53.49	35.90	7.28	2.52	0.80	99.99	
4	4	13	80	97.62	0.76	0.39	0.47	0.24	99.48	Along and north of State Road 622 about half a mile north of Rocky Point.
		7	25	98.66	0.32	0.07	0.35	0.22	99.92	
		6	85	96.14	1.45	0.99	0.43	0.32	99.33	
5	5	1–4	213	97.65	1.35	0.30	0.48	0.14	99.92	Inactive quarry southwest of State Road 622 and 1¼ miles northeast of Indian Rock.
9	8	3	32	97.49	0.85	1.28	0.20 (P_2O_5, 0.063)	0.16	100.04	Along State Road 631 near Limekiln Bridge about 2 miles north of Lexington.
		2	65	97.29	1.06	1.46	0.06 (P_2O_5, 0.098)	0.08	100.04	

11	9	10	70	98.08	0.79	0.84	0.24	0.16	100.17	Along Whistle Creek about ¼ mile north of U. S. Highway 60 and 2 miles northwest of Lexington.
							(P_2O_5, 0.065)			
		9	7	92.72	1.27	5.04	0.60	0.40	100.03	
		8	85	97.29	0.76	1.32	0.44	0.16	100.03	
							(P_2O_5, 0.066)			
		5–7	48	96.49	1.06	1.52	0.40	0.12	99.59	
13	11	1–3	31	96.70	0.85	2.00	0.30	0.12	100.01	Along and northeast of U. S. Highway 60 about 2 miles northwest of Lexington.
							(P_2O_5, 0.045)			
16	12	15–18	160	97.26	0.94	1.04	0.36	0.12	99.72	Along State Road 674 about 2 miles northeast of Murat and 3 miles southwest of Lexington.
		5	135	98.38	0.64	0.72	0.20	0.08	100.06	Along State Road 670 about one mile northeast of Murat and 4 miles southwest of Lexington.
							(P_2O_5, 0.049)			
17	13	4	65	97.89	0.61	0.92	0.32	0.16	99.97	
							(P_2O_5, 0.072)			
		3	35	96.50	1.64	1.48	0.24	0.08	100.02	
							(P_2O_5, 0.08)			
18	14	1–5	236	97.10	1.06	1.32	0.28	0.20	99.96	About half a mile south of State Road 677 and 1 mile southwest of Murat.
		16	109	89.95	1.68	6.68	0.36	0.96	99.53	Along Buffalo Creek near junction of State Highways 251 and 281 about 1½ miles northwest of Murat.
19	15	13–15	131	96.50	1.18	1.52	0.24	0.20	99.64	
		12	37	93.31	1.33	4.52	0.24	0.28	99.68	

[1]Analyses by John H. Yoe are indicated by an asterisk.

TABLE 7.—CHEMICAL COMPOSITION OF CARBONATE ROCKS IN THE JAMES RIVER DISTRICT WEST OF THE BLUE RIDGE, VIRGINIA—Continued

Map No. Pl. 1	Geologic Section			$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	Total	Locality
	No.	Units Sampled	Thickness Feet							
21	.....	.....	60	98.06	0.97	0.60	0.12	0.20	99.95	Near intersection of State Roads 672 and 676 about 4 miles east of Collierstown.
22	17	43,45-46 1-29	22 120	97.10 90.24	0.64 2.48	1.52 6.20	0.36 0.56	0.08 0.12	99.70 99.60	Along Colliers Creek and State Highway 251 about 2½ miles southeast of Collierstown Post Office.
23	18	6-8	76	97.30	0.55	1.40	0.16	0.20	99.61	Along and east of State Road 611 about 3 miles southwest of Murat.
27	20	2-3	56	97.66	1.15	1.12	0.24	0.16	100.33	Along State Highway 251 and Colliers Creek about 1 mile southeast of Collierstown.
28-29	21	5 1-3	60 49	97.26 88.59	0.86 3.70	1.12 6.56	0.40 0.52	0.12 0.28	99.76 99.65	Along Spring Branch about 2½ miles northeast of Rapps Mill.
34	24	2	68	98.26	0.55	0.56	0.28	0.12	99.77	Near State Road 731 about 1 mile northeast of Zack.
38	27	1	48	93.53	2.21	4.04	0.32	0.16	100.26	Along State Road 731 about 2 miles northeast of Rockbridge Baths.

41	29	12 9–11	40 32	93.03 97.06	1.64 0.85	4.52 1.64	0.60 0.32	0.36 0.08	100.15 99.95	Along Kerrs Creek just east of the crossing of State Road 631.
42	30	1	50	97.06	1.60	1.12	0.48	0.08	100.34	At Cyrus McCormick Museum about three-fourths of a mile northwest of Steeles Tavern.
44	.....	.....	100±	98.78	0.40	0.29	0.28	0.14	99.89*	Along Buffalo Creek about 5 miles southwest of Lexington.
45	.....	.....	150 125 190	97.93 95.64 96.30	0.73 2.32 1.35	0.04 1.08 0.68	0.67 0.40 0.97	0.12 0.48 0.14	99.49 99.92 99.44	Vicinity of Purgatory Creek about 2½ miles northeast of Buchanan.
47	32	3	51	93.03	4.94	2.04	0.12	0.24	100.37	Along State Road 670 about 2 miles southwest of Fincastle.
48	33	4	72	94.04	2.97	2.16	0.52 (P_2O_5, 0.016)	0.16	99.86	Along State Road 630 about 1 mile east of Fincastle.
51	34	4–5 2–3 1	112 48 25	97.65 86.17 96.54	0.95 1.65 1.61	0.43 9.77 1.03	0.69 1.16 0.01	0.26 0.62 0.72	99.98 99.37 99.91	Along U. S. Highway 220 and in quarry of Eagle Rock Lime Co., about 1 mile southwest of Eagle Rock.
55	.....	.....	60 50	97.31 91.19	1.50 2.50	0.25 4.99	0.28 0.61	0.24 0.56	99.58 99.85	Exposed east and west of U. S. Highway 220 about 500 feet north of the Bath-Alleghany County line.

TABLE 7.—CHEMICAL COMPOSITION OF CARBONATE ROCKS IN THE JAMES RIVER DISTRICT WEST OF THE BLUE RIDGE, VIRGINIA—Continued

Map No. Pl. 1	Geologic Section			$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	Total	Locality
	No.	Units Sampled	Thickness Feet							
56	36	30 28–29	104 51	96.64 92.68	1.52 2.50	1.00 3.40	0.28 0.93	0.20 0.28	99.64 99.79	West side of U. S. Highway 220 about three-fifths of a mile northeast of Falling Springs Church.
58	Hand Specimen			97.85	0.90	0.48	0.14	0.08	99.45	Falling Springs Lime Co. quarry about 1½ miles southeast of Barber.
59–61	37	5	20	97.45	1.26	0.40	0.29	0.28	99.68	Along State Road 621 between Rich Patch Church and Hooks Mill.
62	38	5 4	18 34	95.74 91.12	2.10 3.74	0.73 3.55	0.31 0.50	0.60 0.80	99.48 99.71	Along C. & O. Railway and U. S. Highway 220 about 1½ miles southeast of Clifton Forge.
64	.....	.....	50	93.31	1.62	3.89	0.80	0.30	99.92	Lowmoor mine about half a mile southwest of Lowmoor and 5 miles southwest of Clifton Forge.
65	.....	.....	50	95.13	1.24	2.47	0.02	0.60	99.46	Along U. S. Highway 60 midway between Lowmoor and Island Ford.
66	40	9 2–4	60 34	92.30 80.58	1.18 2.35	5.05 14.64	0.11 0.70	0.80 1.16	99.44 99.43	Vicinity of Jackson River bridge at Island Ford.

67	41	2	45	96.45	1.00	0.95	0.14	0.92	99.46	Along State Road 600 at Dunlap Beach about 2 miles southeast of Callaghan.
68	.....	.....	50	93.34	1.45	4.26	0.46	0.60	100.11	Along State Road 600 about half a mile southeast of Callaghan.
71	.....	.....	30	85.60	0.87	11.39	0.57	1.04	99.47	Inactive quarry along State Road 600 about 3 miles southwest of Falling Spring.
73	43	6	60	97.86	0.97	0.23	0.20	0.34	99.60	Along Clayton Mill Creek near Marble Valley and 4½ miles southwest of Deerfield.
75	44	8 6 1	38 39 7	93.67 95.44 92.91	1.64 1.92 1.50	2.83 1.30 3.57	0.43 0.48 1.28	0.94 0.38 0.70	99.51 99.52 99.96	Along Calfpasture River at the southeast base of Sideling Hill about 4 miles north of Goshen.
76	45	5 1–2	55 60	92.71 92.88	0.92 1.98	5.04 3.75	0.45 0.60	0.46 0.76	99.58 99.97	Inactive quarry along State Highway 501 about 3 miles northwest of Goshen.
77	46	16–18 2	91 50	93.82 91.60	1.15 2.48	4.08 4.61	0.40 0.70	0.48 0.60	99.93 99.99	Along State Highway 42 and in inactive quarry about 7 miles southwest of Millboro Springs.
80	48	6–7	54	96.64	1.56	0.58	0.69	0.04	99.51	Along State Road 683 about 2 miles southwest of Craigsville.

TABLE 7.—CHEMICAL COMPOSITION OF CARBONATE ROCKS IN THE JAMES RIVER DISTRICT WEST OF THE BLUE RIDGE, VIRGINIA—Continued

Map No. Pl. 1	Geologic Section			$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	Total	Locality
	No.	Units Sampled	Thickness Feet							
81	49	12–13	61	96.65	1.27	0.95	0.62	0.20	99.69	Inactive quarry one-fourth of a mile southeast of the C. & O. Railway at Bells Valley.
82	50	9–10	298	54.16	42.01	3.48	0.24	0.48	100.37	Vicinity of Natural Bridge Station about 100 yards northeast of State Highway 249 and west of State Road 628.
		6–7	519	54.56	42.98	1.44	0.48	0.40	99.97	
				(P_2O_5, 0.01; Na_2O, 0.054; K_2O, 0.047)						
		1–5	391	55.98	42.05	1.00	0.24	1.08	100.35	
83	51	1–4	603	54.30	43.91	1.15	0.53	0.38	100.40	Along C. & O. Railway at Natural Bridge Station.
					(Na_2O, 0.10; K_2O, 0.03)					
84	52	7–9	535	52.37	40.90	4.84	1.58	0.78	100.47	Along State Road 1001 and tributary to James River about one-fourth mile west of Natural Bridge Station.
		1–6	756	58.17	40.20	1.00	0.25	0.58	100.20	
86	.....	.....	150	55.89	43.41	0.20	0.36	0.12	99.98	Along C. & O. Railway about three-fourths of a mile south of Rocky Point.
87	53	3	530	51.03	39.06	9.04	0.72	0.56	100.41	Along N. & W. Railway about 2 miles northeast of Buchanan.
		2	112	51.23	36.98	10.28	0.80	0.88	100.17	
		1	155	52.02	39.83	7.52	0.48	0.36	100.21	

88	54	2-4,6	688	54.51	43.65	1.03	0.41	0.38	100.13	About 500 feet northeast of the James River Hydrate & Supply Co. quarry and 1½ miles northeast of Buchanan.
						(Na_2O, 0.12; K_2O, 0.03)				
90	.....	From bin	.....	55.87	42.98	0.35	0.18	0.66	100.04	Liberty Limestone Corporation quarry along James River about half a mile east of Buchanan.
92	55	2	336	54.60	41.08	3.50	0.18	0.64	100.02	About half a mile east of the N. & W. Railway and 1 mile south of Buchanan.
						(P_2O_5, 0.02)				
		1	395	54.80	40.02	4.48	0.28	0.36	99.95	
						(P_2O_5, 0.019)				
95	.....	.....	125	54.60	42.79	2.04	0.20	0.44	100.07	Near State Road 645 about 5 miles southwest of Buchanan and 2 miles east of Lithia.
96	Com scat over	posite sa tered exp an area o	mple of osures f an acre	55.49	43.24	0.64	0.46	0.61	100.44	Arnolds Valley about 2½ miles south of Natural Bridge Station.
.....	.....	.....	100	56.21	41.29	1.56	0.87	0.24	100.17*	Near intersection of State Roads 731 and 724 about 2 miles northwest of Brownsburg.
22	56	2–10	557	71.68	4.20	20.24	0.48	1.00	97.60	Along Colliers Creek and State Highway 251 about 2½ miles southeast of Collierstown Post Office.
	Han	d specim	en of shale	57.91	5.66	25.27	9.31	0.79	98.94*	
	Han	d specim	en of lime-stone	86.72	2.93	10.50	1.80	0.63	102.58*	

TABLE 7.—CHEMICAL COMPOSITION OF CARBONATE ROCKS IN THE JAMES RIVER DISTRICT WEST OF THE BLUE RIDGE, VIRGINIA—Continued

Map No. Pl. 1	Geologic Section			$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	Total	Locality
	No.	Units Sampled	Thickness Feet							
25	57	4–8	269	86.78	2.23	8.54	1.43	0.44	99.42	About half a mile south of Dunkard Church and 7 miles southwest of Natural Bridge.
97	.....	.....	150	82.77	6.94	8.76	0.56	0.52	99.55	Barger quarry in the eastern environs of Lexington along U. S. Highway 60.
100	59	28–35	317	54.56	37.50	7.40	0.52	0.44	100.42	Beginning just east of Steeles Tavern and extending northwestward along State Road 606.
		16–26	296	50.94	36.86	11.40	0.68	0.44	100.32	
		4–15	593	52.34	39.32	7.84	0.28	0.56	100.34	
		2–3	490	88.59	5.30	5.36	0.32	0.12	99.69	
101	60	1–3	494	87.79	6.06	4.80	0.44	0.20	99.29	Along State Road 711 about 1¼ miles southeast of Fairfield and 4 miles east of Timber Ridge.
102	61	28–32	199	54.36	39.40	5.72	0.16	0.56	100.20	Along State Road 614 between U. S. Highway 11 and Indian Rock.
		18–27	266	55.16	34.83	9.48	0.24	0.60	100.31	
103	62	8–23	262	53.01	36.88	9.52	0.12	0.60	100.13	Along Colliers Creek and State Highway 251 about 2 miles southeast of Collierstown Post Office.
		1–7	113	53.60	38.56	7.12	0.36	0.48	100.12	

104	.....	.....	150	52.14	40.37	6.84	0.52	0.48	100.35	Along State Highway 252 about 1 mile south of Newport.
110	66	83	125	88.79	3.73	6.80	0.40	0.28	100.00	Along State Highway 56 extending southeast of Steeles Tavern.
		41–46	282	52.14	32.38	14.12	0.56	0.96	100.16	
		27–32	426	52.96	37.22	9.00	0.52	0.88	100.58	
111	67	55–58	211	76.92	6.57	15.08	0.92	0.72	100.21	Along C. & O. Railway and N. & W. Railway extending northwest of Buena Vista.
		51–53	187	72.30	9.42	17.16	0.72	0.60	100.20	
		46–50	700	80.34	6.33	12.40	0.40	0.64	100.11	
		25–34	298	51.66	38.37	9.12	0.08	1.04	100.27	
		23–24	404	50.54	39.05	9.44	0.52	0.68	100.23	
112	.....	.....	200	53.56	42.53	3.56	0.32	0.44	100.41	East and west of State Road 608 in the vicinity of Buffalo Forge.
116	70	1–4	180	56.56	33.56	9.36	0.40	0.60	100.48	Quarry along U. S. Highway 11 about 5 miles northeast of Lexington.
117	71	57–64	398	51.34	38.02	9.68	0.52	0.64	100.20	Along State Road 675 about 2½ miles east of Newport.
		36–47	581	52.04	38.37	9.40	0.08	0.56	100.45	
118	.....	.....	75	83.17	6.36	9.16	0.56	0.68	99.93	Along State Highway 251 about 1½ miles northeast of Newport.
.....	.....	.....	150	51.34	39.76	7.64	0.36	1.32	100.42	Along N. & W. Railway about 300 yards southeast of the Lone Jack quarry and 4 miles northeast of Natural Bridge Station.

TABLE 7.—CHEMICAL COMPOSITION OF CARBONATE ROCKS IN THE JAMES RIVER DISTRICT WEST OF THE BLUE RIDGE, VIRGINIA—Continued

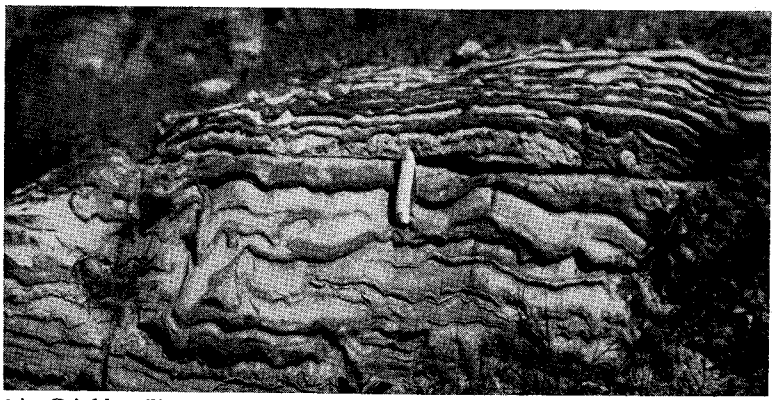
Map No. Pl. 1	Geologic Section			$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	Total	Locality
	No.	Units Sampled	Thickness Feet							
119	72	5–8	626	54.56	38.62	3.85	2.35	0.88	100.26	Along C. & O. Railway and James River about 2½ miles southeast of Eagle Rock.
		1–4	631	54.16	40.65	3.62	0.81	1.14	100.38	
			700	49.42	40.03	7.06	2.66	0.50	100.44	
					(Na_2O, 0.15; K_2O, 0.62)					

TABLE 8.—PHYSICAL TESTS OF SELECTED SAMPLES OF COARSE AGGREGATE FROM THE JAMES RIVER DISTRICT[1]

Map No. Pl. 1	Geologic Section			Physical Properties				Classification	
	No.	Units Sampled	Thickness Feet	Specific Gravity	Absorption	Soundness	Los Angeles Abrasion loss	Grade	Formation
4	4	6	85	2.70	0.3	O.K.	31.0	A	New Market limestone
17	13	4–5	200	2.70	0.5	O.K.	32.0	A	Lincolnshire limestone

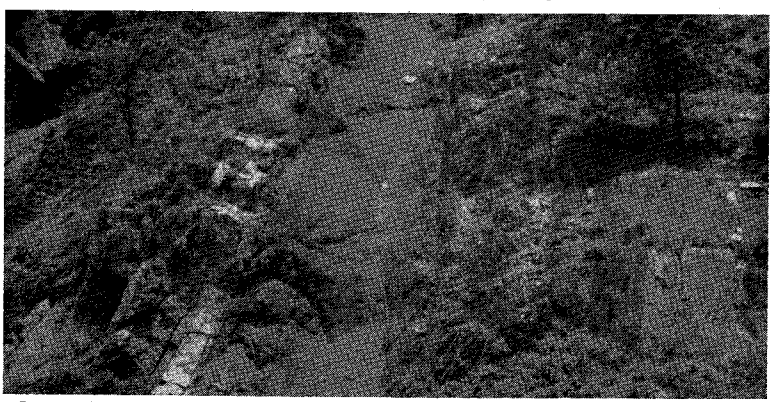
82	50	6	268	2.84	0.4	O.K.	23.0	A	Shady dolomite
86	.....	.....	50	2.84	0.4	O.K.	20.0	A	Shady dolomite
97	.....	.....	100	2.78	0.6	O.K.	20.0	A	Edinburg limestone
100	59	4–15	593	2.85	0.6	O.K.	23.0	A	Beekmantown dolomite
102	61	18–27	266	2.78	0.5	O.K.	21.0	A	Beekmantown dolomite
100	66	27–32	426	2.78	0.4	O.K.	23.0	A	Elbrook dolomite
		41–46	282	2.78	0.3	O.K.	18.0	A	
111	67	25–34	298	2.81	0.5	O.K.	18.0	A	Elbrook dolomite
117	71	66–68	105	2.76	0.7	O.K.	26.8	A	Conococheague limestone and dolomite
118	.....	.....	75	2.69	0.3	O.K.	20.0	A	Elbrook limestone
119	72	1–8	1257	2.86	0.5	O.K.	24.0	A	Elbrook dolomite

[1]Laboratory tests made by the Division of Tests, Virginia Department of Highways.

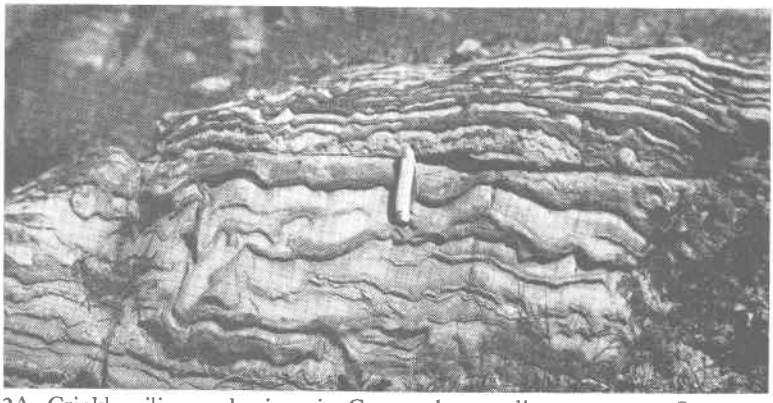


2A. Crinkly siliceous laminae in Conococheague limestone near Staunton, Augusta County, Virginia.

2B. Weathered Elbrook dolomite along U. S. Highway 11 about half a mile south of Buffalo Creek, Rockbridge County, Virginia.



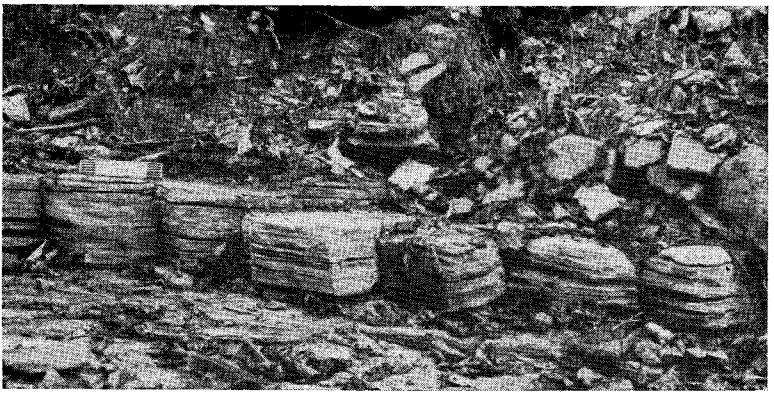
2C. Hackly weathering red shale and impure dolomite in the upper part of the Waynesboro formation in the vicinity of Indian Rock, Botetourt County, Virginia.



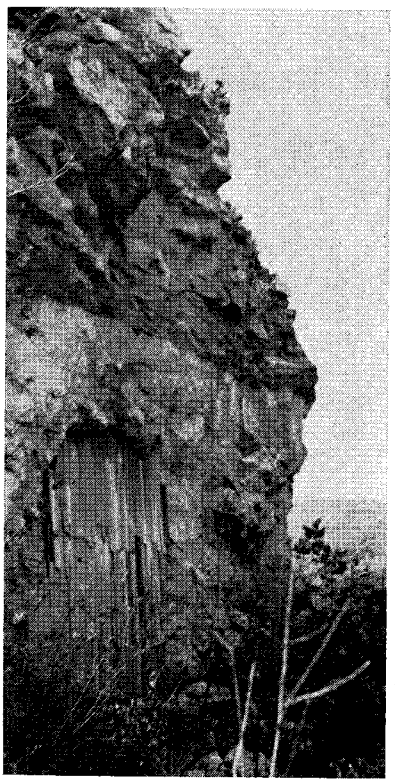
2A. Crinkly siliceous laminae in Conococheague limestone near Staunton, Augusta County, Virginia.

2B. Weathered Elbrook dolomite along U. S. Highway 11 about half a mile south of Buffalo Creek, Rockbridge County, Virginia.

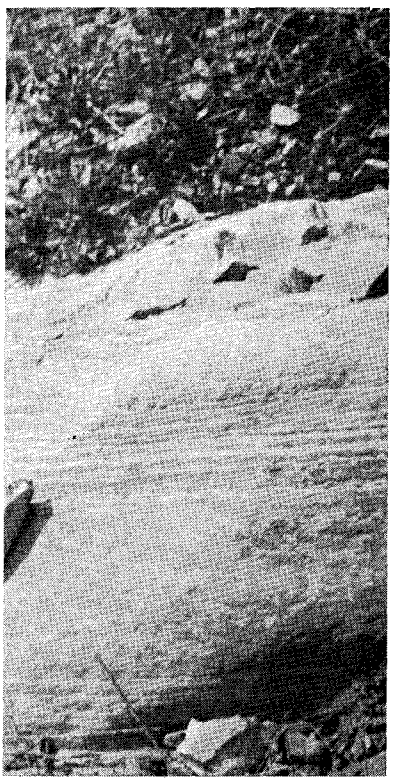
2C. Hackly weathering red shale and impure dolomite in the upper part of the Waynesboro formation in the vicinity of Indian Rock, Botetourt County, Virginia.



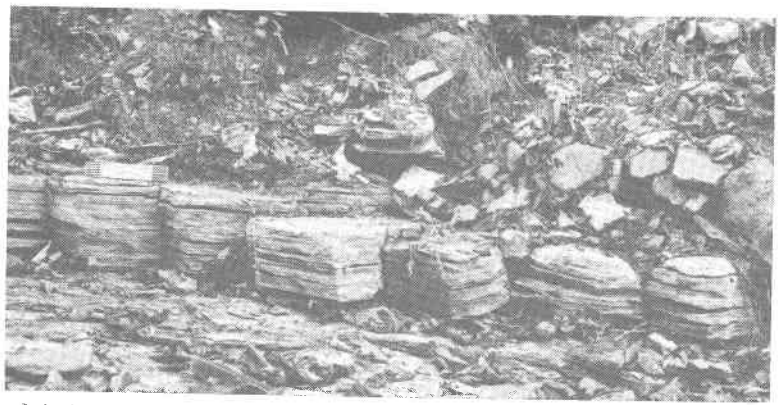
3A. Jointing in Tonoloway limestone along State Highway 42 about 4 miles southwest of Millboro Springs, Bath County, Virginia.



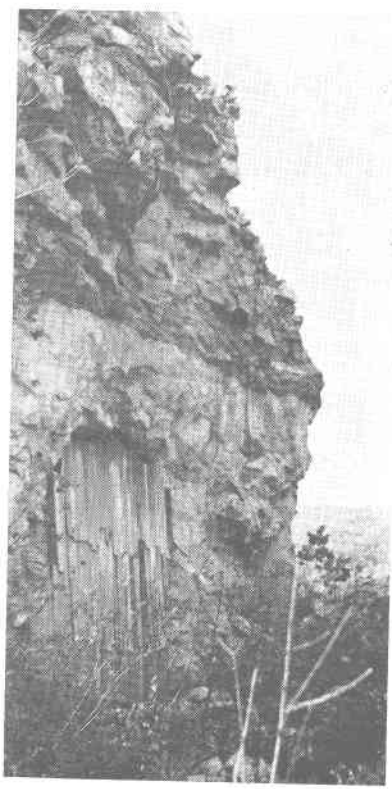
3B. Inactive mine in the vicinity of Eagle Rock, Botetourt County, showing Beekmantown dolomite (dark) on Ordovician limestone.



3C. Striped weathering impure Ordovician limestone overlying Beekmantown dolomite near the southwestern end of Warm Springs Valley, Alleghany County, Virginia.

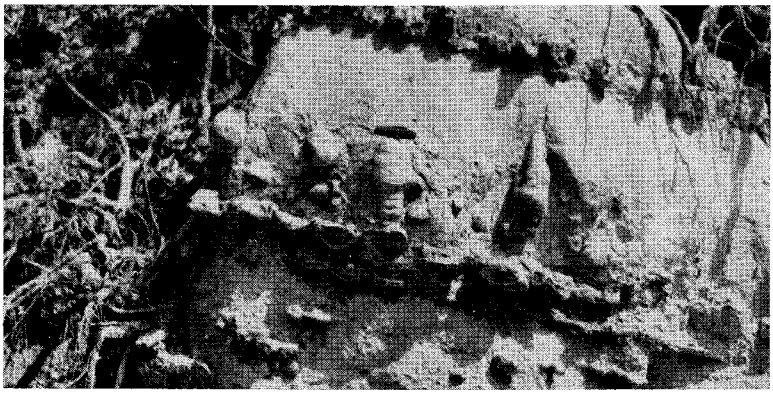


3A. Jointing in Tonoloway limestone along State Highway 42 about 4 miles southwest of Millboro Springs, Bath County, Virginia.

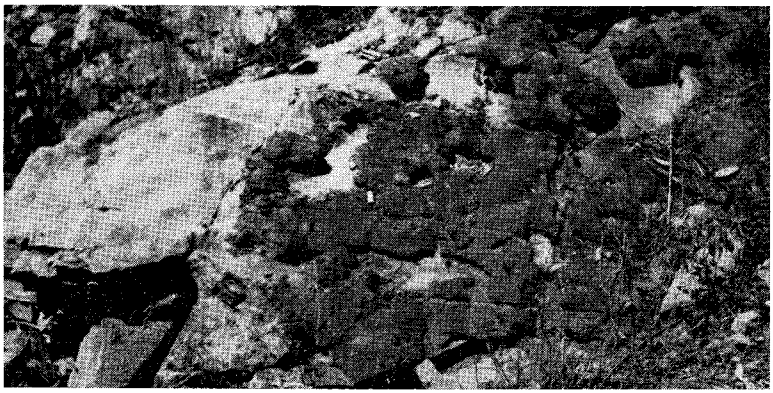


3B. Inactive mine in the vicinity of Eagle Rock, Botetourt County, showing Beekmantown dolomite (dark) on Ordovician limestone.

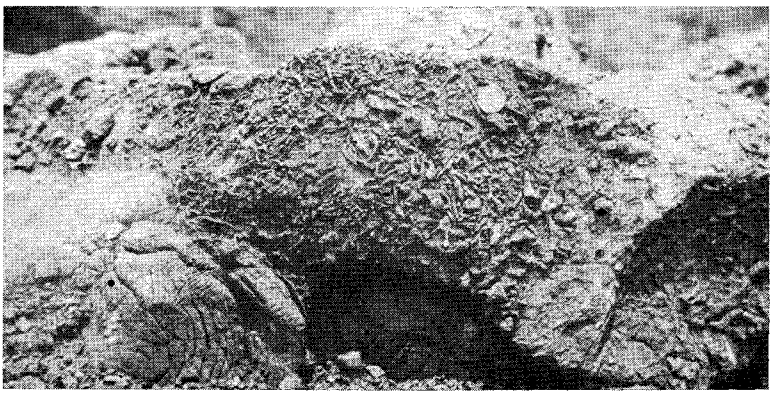
3C. Striped weathering impure Ordovician limestone overlying Beekmantown dolomite near the southwestern end of Warm Springs Valley, Alleghany County, Virginia.



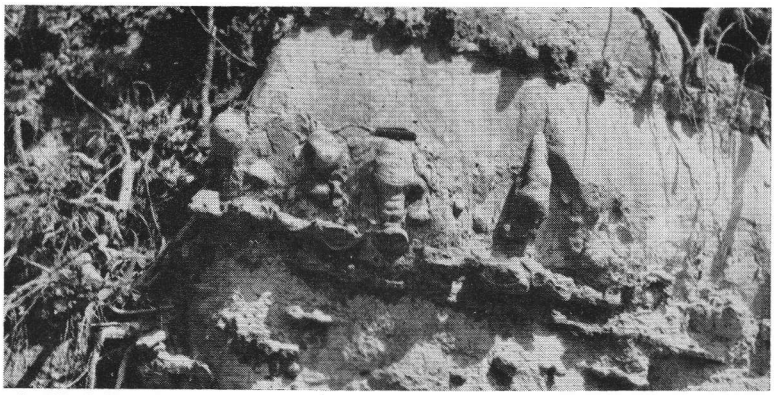
4A. Nodular chert in the New Market limestone along Road 672 about 3 miles northeast of Collierstown, Rockbridge County, Virginia.



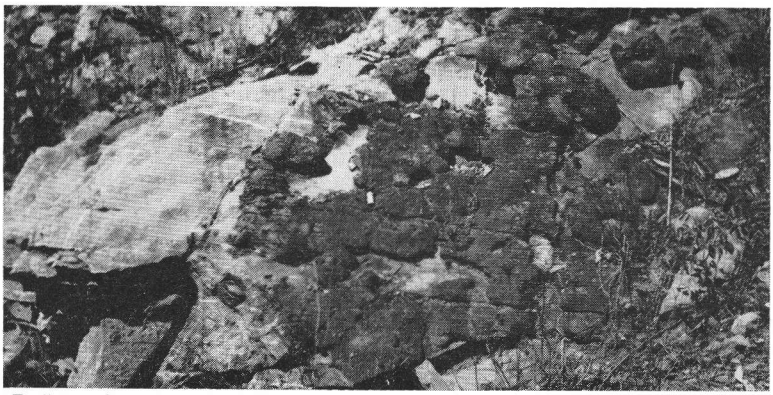
4B. Irregular masses of chert along bedding surfaces in the lower part of the Licking Creek limestone in the vicinity of Craigsville, Augusta County, Virginia.



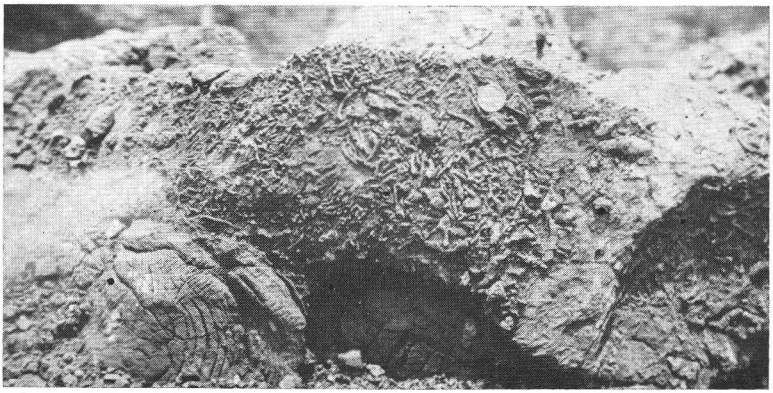
4C. Keyser limestone with fossils (bioherm) in the eastern environs of Clifton Forge, Alleghany County, Virginia.



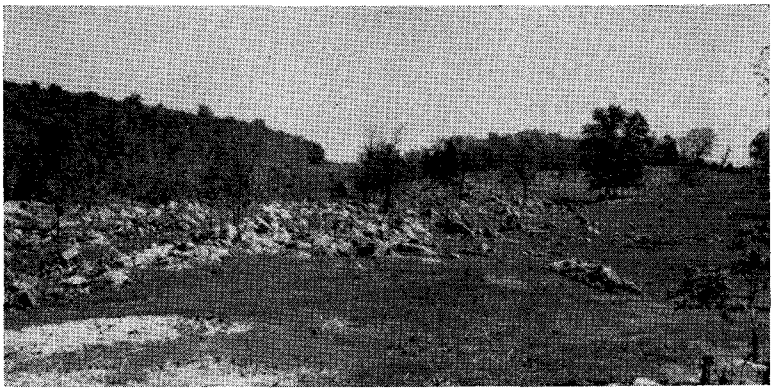
4A. Nodular chert in the New Market limestone along Road 672 about 3 miles northeast of Collierstown, Rockbridge County, Virginia.



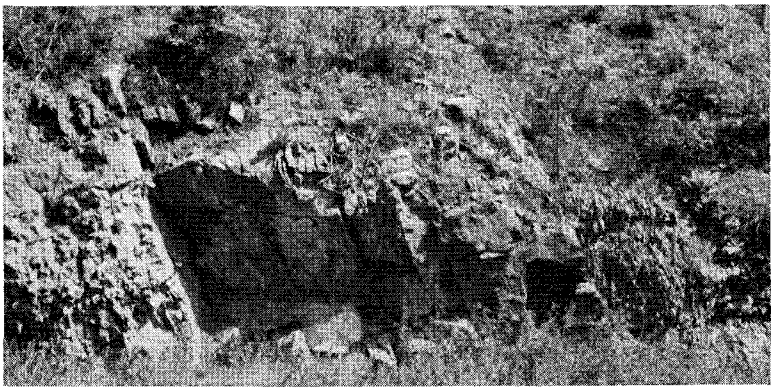
4B. Irregular masses of chert along bedding surfaces in the lower part of the Licking Creek limestone in the vicinity of Craigsville, Augusta County, Virginia.



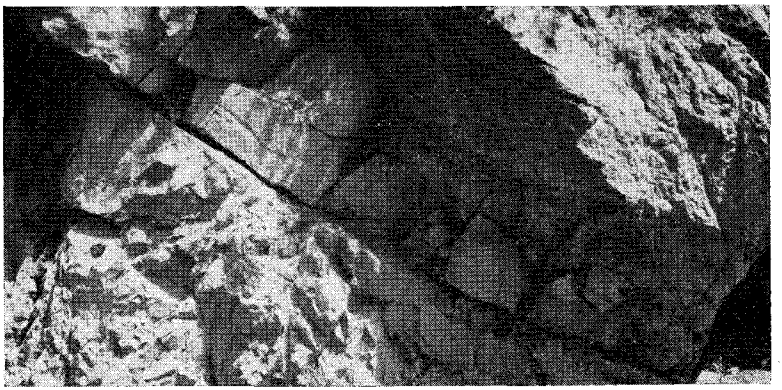
4C. Keyser limestone with fossils (bioherm) in the eastern environs of Clifton Forge, Alleghany County, Virginia.



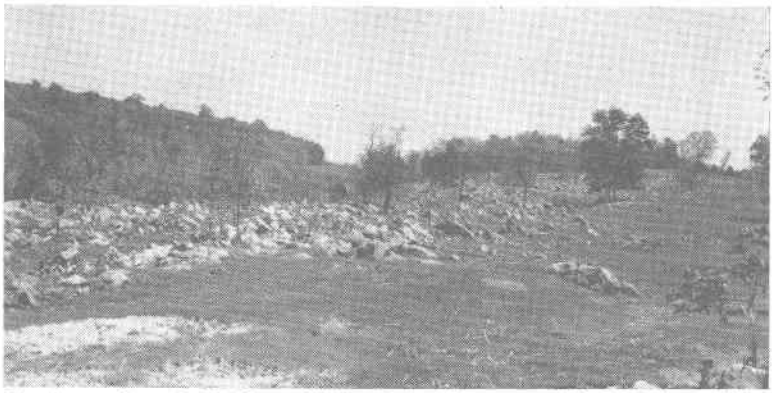
5A. Approximately 200 feet of high-calcium limestone (Murat facies of Lincolnshire) exposed along Road 670 about one mile northeast of Murat, Rockbridge County, Virginia.



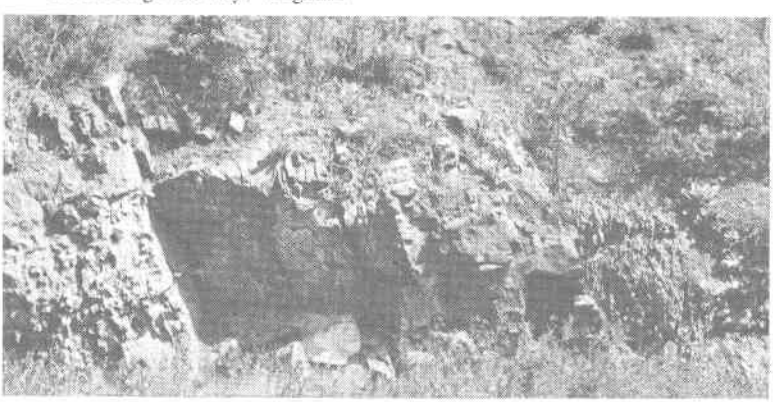
5B. Thin intercalation of coarse-grained limestone (Murat facies) in cobbly weathering impure Lincolnshire limestone along Colliers Creek about 2½ miles southeast of Collierstown, Rockbridge County, Virginia.



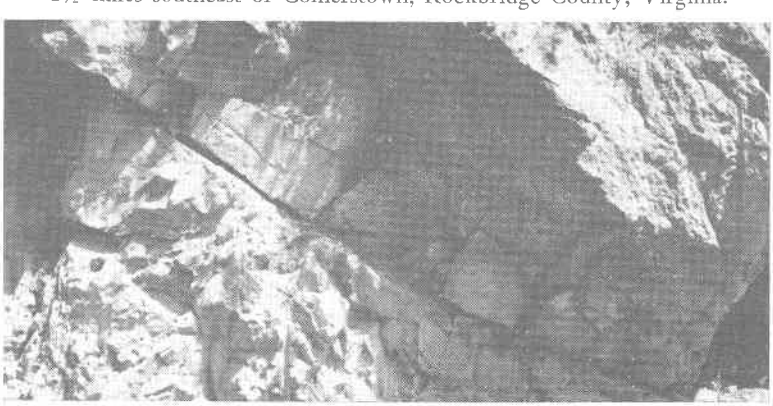
5C. Contact of New Market limestone with overlying cherty Whistle Creek limestone along Colliers Creek about 2 miles southeast of Collierstown, Rockbridge County, Virginia.



5A. Approximately 200 feet of high-calcium limestone (Murat facies of Lincolnshire) exposed along Road 670 about one mile northeast of Murat, Rockbridge County, Virginia.



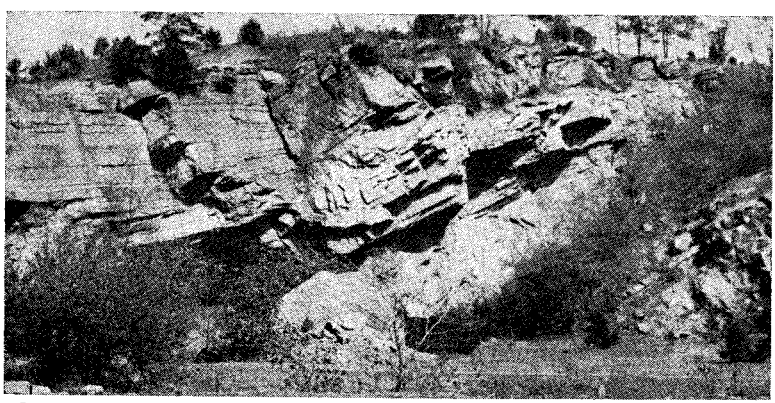
5B. Thin intercalation of coarse-grained limestone (Murat facies) in cobbly weathering impure Lincolnshire limestone along Colliers Creek about 2½ miles southeast of Collierstown, Rockbridge County, Virginia.



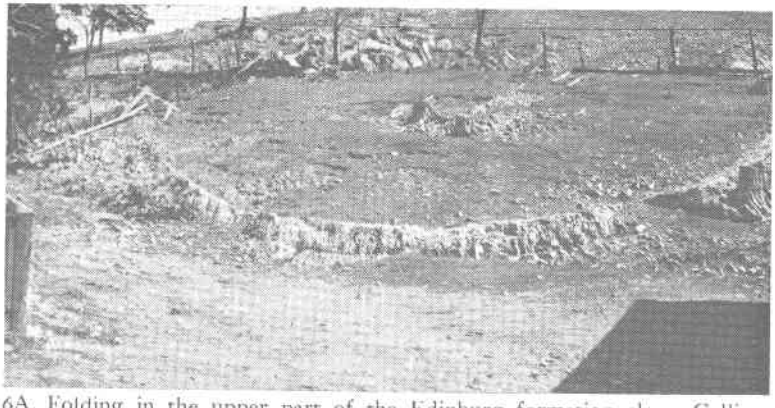
5C. Contact of New Market limestone with overlying cherty Whistle Creek limestone along Colliers Creek about 2 miles southeast of Collierstown, Rockbridge County, Virginia.

6A. Folding in the upper part of the Edinburg formation along Colliers Creek about 3 miles southeast of Collierstown, Rockbridge County, Va.

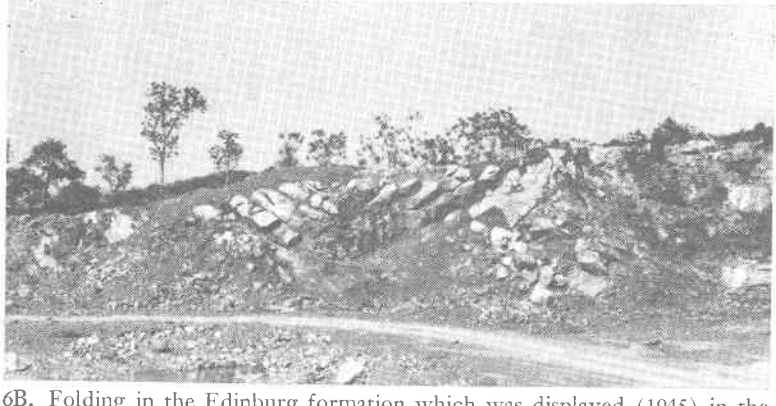
6B. Folding in the Edinburg formation which was displayed (1945) in the Barger quarry along U. S. Highway 60 just east of Lexington. Rockbridge County, Va.



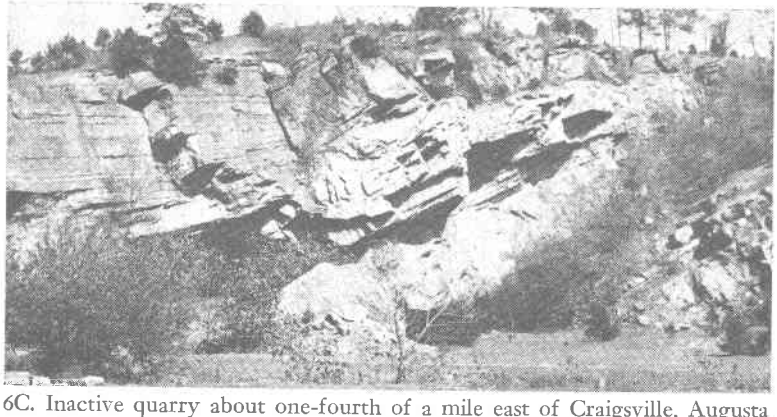
6C. Inactive quarry about one-fourth of a mile east of Craigsville, Augusta County, Va., showing Coeymans limestone (light-colored) overlain by dark-gray, cherty limestones.



6A. Folding in the upper part of the Edinburg formation along Colliers Creek about 3 miles southeast of Collierstown, Rockbridge County, Va.



6B. Folding in the Edinburg formation which was displayed (1945) in the Barger quarry along U. S. Highway 60 just east of Lexington. Rockbridge County, Va.



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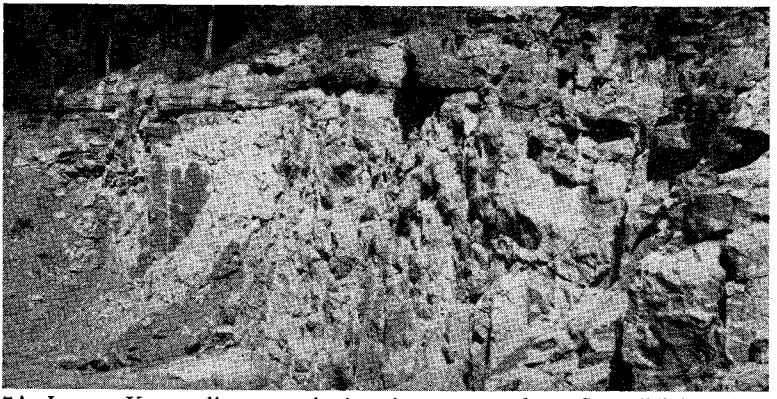
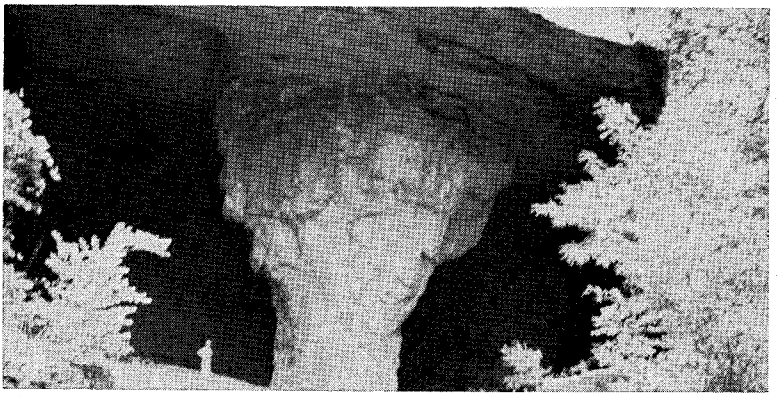
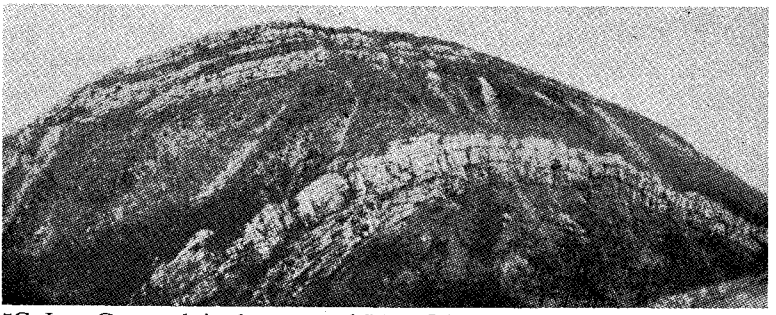


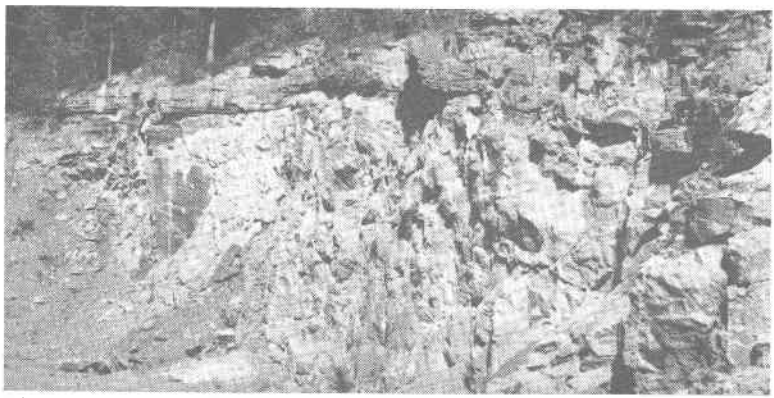
7A. Lower Keyser limestone in inactive quarry along State Highway 42 about 4 miles southwest of Millboro Springs, Bath County, Va.



7B. Upper Licking Creek limestone comprising column in Lowmoor mine about half a mile southwest of the railroad junction at Lowmoor, Alleghany County, Va.



7C. Iron Gate arch in the gorge of James River through Rich Patch Mountain, about 1½ miles southeast of Clifton Forge, Alleghany County, Va. (Photo from Butts, 1940, Pl. 55A).



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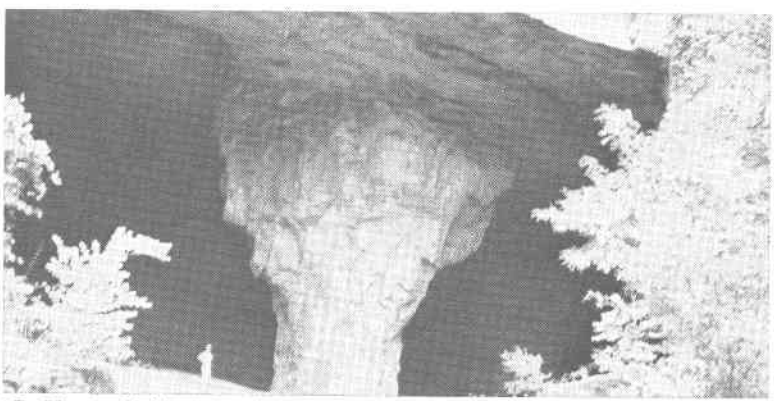

7B. Upper Licking Creek limestone comprising column in Lowmoor mine about half a mile southwest of the railroad junction at Lowmoor, Alleghany County, Va.

7C. Iron Gate arch in the gorge of James River through Rich Patch Mountain, about 1½ miles southeast of Clifton Forge, Alleghany County, Va. (Photo from Butts, 1940, Pl. 55A).

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DIVISION OF MINERAL RESOURCES
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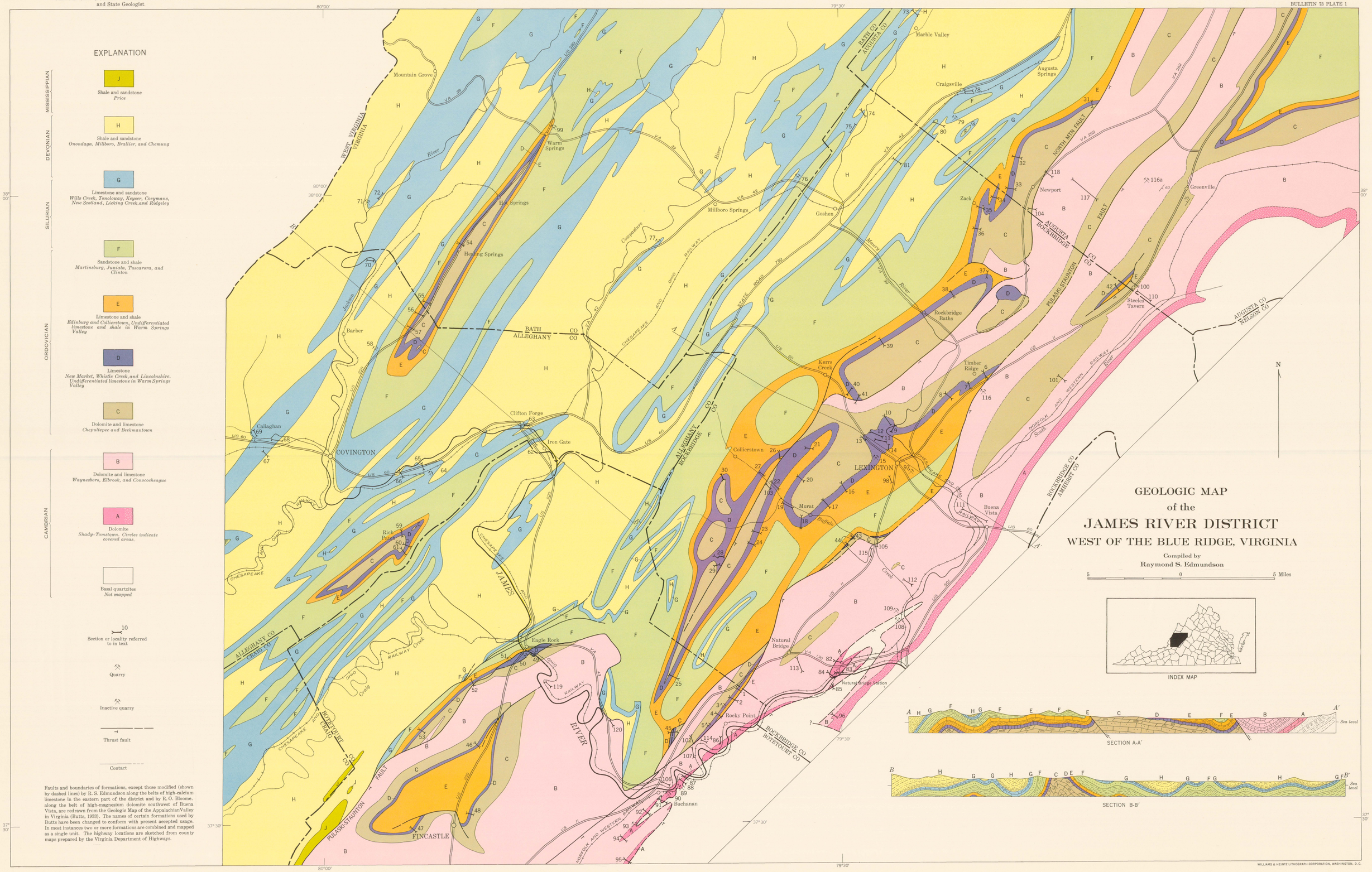
and State Geologist



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